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IMPLEMENTATION OF AREA NAVIGATION IN THE NATIONAL AIRSPACE SYSTEM: an assessment of RNAV Task Force Concepts and Payoffs

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16. Abstract

This document presents the results of a three year study effort to define the cost and operational impact, and to assess the economic benefits which are expected to accrue to the ATC system and various users of the National Airspace System as a result of the implementation of Area Navigation.

Previous impact analyses are expanded to include the primary aspects of ATC system operation and to include a broad spectrum of user groups, route structures, and types of operation. System impact results are presented pertaining to slant range effects, VORTAC requirements, ATC automation, airspace capacity, route development, charting, flight inspection, VNAV, controller training, and controller productivity.

User impact results are presented in terms of fuel and time increment benefits for several classes of users, comparing 2D RNAV to VOR in the high and low altitude structures, and comparing 2D, 3D and 4D RNAV to VOR/radar vectors in the terminal area. Estimates are made of total annual savings due to RNAV, and an analysis of user equipment cost versus benefits is presented.

The results of the user and system impact analyses, together with results of related system studies in the areas of avionics standards, waypoint standards, route design, and flight technical error are utilized to develop an RNAV operational concept. The system design and implementation concepts presented are based on the Task Force concept, but modified as appropriate to insure maximum benefits to the ATC system and a broad spectrum of users of the National Airspace system.

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PREFACE

The Systems Research and Development Service of the Federal Aviation Administration has undertaken a program to assess the technical and economic impact of Area Navigation on the ATC System and the users of the National Airspace System. This work was performed under the RNAV Technical Support Contract to Systems Control, Inc. (Contract No. DOT-FA-72-WA-3098 Task Order No. 008). The work was performed by the Champlain Technology Industries Division (CTI) and the Aeronautical and Marine Systems Division (A&M) of Systems Control, Inc. (Vt), a subsidiary of Systems Control, Inc.

The FAA Technical Monitor for this work was D. M. Brandewie and the Technical Support Program Manager was D. W. Richardson of CTI. The Project Manager and principal author of this document was W. H. Clark of CTI.

This document is a final report containing the results of economic impact studies and the description of an RNAV implementation concept.

Particular acknowledgement to the members of the technical staffs of CTI and A&M is given to:

W. H. Clark	(Project Management, Study Methodology, VNAV Analysis, User Benefit Analysis, Route Length Analysis, Operational Concept)
E. H. Bolz	(Terminal Area Analysis, 4D Analysis, User Cost and Requirements Analysis, Slant Range Analysis, Terminal VORTAC Analysis, Automation Analysis)
H. L. Solomon and A. R. Stephenson	(Low Altitude Route Length Analysis, Weather Route Simulation Analysis, High Altitude VORTAC Analysis)

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IMPLEMENTATION OF AREA NAVIGATION IN
THE NATIONAL AIRSPACE SYSTEM:

An Assessment of RNAV Task Force Concepts and Payoffs

1.0 EXECUTIVE SUMMARY

1.1 PROGRAM SCOPE AND OBJECTIVES

This report contains the results of a three year study effort to define the cost and operational impact, and to assess the economic benefits which are expected to accrue to the ATC system and the various users of the National Airspace System as a result of the implementation of Area Navigation. The results of this study include benefits and costs for the complete spectrum of primary users of the National Airspace System and for the ATC System, and the definition of a system concept evolved from the FAA/Industry RNAV Task Force [1] concept which will allow a timely evolution to an all-RNAV environment. Although the ATC system and user costs and the ATC system savings derived in this report are based on an RNAV system which uses VORTAC as the position reference, RNAV is considered to be a generic descriptor of a random navigation system which can utilize navigation sensors other than VORTAC, and which will result in similar savings.

Costs and benefits are derived on a per aircraft basis as well as an annual aggregate basis. Annual benefits are shown for both an all-RNAV environment and for the transition period of mixed RNAV/VOR operations. The system concept which is defined includes a phased transition from VOR to RNAV, such as suggested by the Task Force, but the timing of the phases is dependent upon user demand rather than the fixed calendar periods recommended by the Task Force.

In assessing the impact of area navigation, the system design concept to be implemented will determine, to a great extent, the operational impact on both the system and the users and the degree of payoff for each. A series of related studies over the past three years, both completed and ongoing, have been aimed at the solution of the problem areas described in the Task Force Report [1] and the overall evaluation of Task Force RNAV concepts. These studies have examined terminal area design concepts [2], the development of waypoint designation standards [3], enroute design criteria [4], route width requirements [5], the application of 4D RNAV in the terminal area [6], the development of Avionics Standards [7], the quantifying of Flight Technical Error [8], the impact of mixed VOR/RNAV environments [9,10,11], various RNAV system features such as parallel offsets and paralleling in turns [7], and the application of VNAV in the terminal area [2,11]. Previous economic impact studies [12] have examined the terminal area and high altitude operations of trunk and local service carriers, the impact of those operations in a mixed VOR/RNAV environment, and the anticipated long term payoff of an all-RNAV environment. Other studies [1,13], made a preliminary assessment of Navaid requirements for the support of an RNAV and preplanned direct structure as well as terminal area RNAV designs. The impact on controller communications workload was also determined [9,11,12].

The major objectives of this report are as follows:

1) Expand preliminary analyses of ATC system impact to include the primary aspects of ATC system operation.

2) Expand the preliminary user payoff analysis to include a broader spectrum of user groups, route structures, and types of operation, and to include latest available information.

3) Summarize the results of other RNAV system studies as they relate to the elements of system design which bear on the economic and operational impact on the users and the system.

4) Based on the results of related system studies and on a trade-off of impact vs system design elements, expand, clarify and modify as necessary the Task Force RNAV system operational concept, develop a total system design concept, and generate an implementation scenario which will support these concepts.

1.2 METHOD OF APPROACH

The final payoff analysis included in this report considered the three nominal RNAV implementation periods, both from the viewpoint of potential economic benefits to the user and the system and that of the ability of the system and user to function efficiently in the mixed VOR/RNAV environment. The payoff analysis effort concentrated on an expansion of the previous results relating to the ultimate costs and benefits associated with long term implementation rather than the transition phases, but also included the estimation of transition period benefits.

User Impact

The preliminary user benefit analyses [12] were limited to fuel and time effects of route length, altitude profiles, and conflict resolution as they applied to airlines jet aircraft operation. The current effort expanded that analysis in several ways.

A broader spectrum of users were considered, including business aircraft, general aviation, and military aircraft. The fuel and time savings achieved in enroute and terminal area operations by airline aircraft [12] were expanded to include the remainder of the primary users of the National Airspace System.

Preliminary terminal area designs were reviewed with users and were discussed with the respective FAA regions/facilities and were modified as appropriate [2]. The modifications also involved an iterative procedure designed to optimize the designs from a user economic point of view. A route structure based on one of the modified designs (New York) was utilized in a real time simulation at NAFEC [11] to further explore the benefits available to the user through the use of RNAV and to determine if fixed gradient VNAV routes provided any operational advantage to the user in the terminal area. Finally, annualized benefits due to altitude profile and route length effects were estimated by extrapolation for all CONUS terminal areas, and the incremental effects of 3D and 4D RNAV were determined. In the previous effort [12] route length savings were computed for both high altitude charted RNAV and

preplanned direct RNAV based on a nominal 150 airport pair route structure. This analysis has been updated and expanded in four ways: 1) an expanded high altitude structure containing 429 airport pairs was utilized; 2) a sample low altitude structure was developed, analyzed, and the results extrapolated to obtain an estimate of CONUS operation; 3) the no-wind route length analysis of the high altitude structure was calibrated by a simulation and analysis of RNAV weather routes compared with existing VOR weather routes; 4) the route length analysis of the high altitude structure was further calibrated by including the impact of restricted areas on the RNAV structure.

A series of interviews was conducted with various user groups to determine their respective views concerning RNAV implementation and to identify cost elements associated with that implementation as well as areas of potential benefit. Interviews were conducted with representatives of the National Business Aircraft Association, Aircraft Owners and Pilots Association, Helicopter Association of America, General Aviation Manufacturers Association, U.S. Army, U.S. Air Force, U.S. Navy, and U.S. Coast Guard. The information obtained was used to identify single event benefits, to calibrate the assumptions necessary in the analysis of enroute and terminal area fuel and time benefits, and to assess the overall impact of RNAV implementation on each of the user groups. The benefits available to six individual airlines, based on current schedule and frequency of operation, were also estimated.

ATC System Impact

Previous efforts [12,13] investigated the ability of the controller to operate in a mixed VOR/RNAV environment, estimated controller productivity increases due to RNAV, studied the effects of RNAV on enroute and terminal area capacity, and made preliminary estimates of terminal area and high altitude enroute requirements for VORTAC coverage to support an RNAV structure compared with that to support a VOR structure expanded to accommodate an equal amount of traffic.

In the current effort, the enroute high altitude VORTAC requirements analysis was expanded to include upgrading of VORTAC stations as well as the addition of new stations. The preliminary analysis of terminal area VORTAC requirements [13] was expanded to include a more detailed assessment of the relationship between traffic density, fix requirements, and VORTAC requirements. The analysis of the effects of slant range error which was initiated in Reference 7 was expanded through flight tests, additional simulation and additional analysis and the results applied to the assessment of low altitude and terminal area route design.

An assessment was made of RNAV route development requirements, including the requirement for a coordinated effort to produce optimum high altitude, low altitude, terminal and transition designs, from which individual routes can be implemented during the transition periods. This analysis included consideration of charting, ATC automation, video map requirements, VORTAC coverage and flight checking, and airspace capacity.

The impact of charted routes and preplanned direct RNAV operations on both enroute and terminal area automation requirements was investigated. Potential impact was considered with respect to storage and computational requirements for metering and sequencing, route definition, flow control, and automatic conflict prediction and resolution. Both hardware and software impact was assessed and an overview of potential problem areas and elements of probable impact was prepared.

A preliminary assessment of the impact of RNAV implementation on controller training requirements was made, including recognition of various levels of RNAV equipment capability, and the utilization of RNAV procedures and phraseology.

Finally, an additional real time simulation was conducted at NAFEC [11] to evaluate the impact of various levels of RNAV, VNAV, and radar vectored traffic on system performance and capacity to determine the effect of fixed gradient VNAV routes or controller workload and system performance.

RNAV Operational Concepts

The RNAV concept as envisioned by the Task Force [1] involved several elements which could have significant economic and operational impact (penalty or benefit) on the user and/or the ATC system. The operational aspects of these elements have been analyzed in this and other studies [12,13]. The results of these studies were utilized to develop an overall operational concept for area navigation which is based on the Task Force concept, but which utilizes the results of subsequent analyses, as were recommended by the Task Force. The resultant operational concept is intended to form a baseline for the implementation of RNAV in a manner most beneficial to the ATC system and a broad spectrum of users of the National Airspace System.

An analysis was conducted of cost versus capability of existing area navigation systems, with capability delineated in a manner which relates to operational utility, pilot workload, and economic benefit. The Task Force proposed that RNAV be the "price of entry" to high and medium density terminal areas in the post-1982 time period. An analysis was made of the relative numbers of aircraft, by type and use, which would require RNAV equipment as a result of each of several candidate definitions of a "terminal area" for this purpose.

A detailed analysis was made of various VNAV concepts, from the viewpoints of airspace capacity, user economics, user operational utility, ATC system considerations, and controller workload. The technical and operational aspects of turn anticipation, paralleling through turns, waypoint designation and storage, parallel offsets, and slant range correction were considered. Terminal area and enroute airspace design concepts were developed, based on results of terminal area design studies, enroute studies, slant range considerations, VNAV analyses, and route width requirements studies.

The intent was not to find a "compromise" solution which would not fully satisfy any individual user, but rather to describe a concept which recognizes several levels of RNAV/VNAV capability, allows their use without compromise to the system as a whole, and provides maximum benefits for all users.

1.3 USER RELATED RESULTS

The benefits available to the various users of the National Airspace System in an all RNAV environment accrue primarily from the economic and operational advantages of a more efficient and ordered route structure both enroute and in the terminal area. These benefits, which are heavily dependent upon the operational concept which is implemented, are derived through reduction in route lengths, improvement in vertical flight profiles, reduction in arrival holding delays, reduced pilot workload, and improvement in the availability and safety of instrument approaches.

The savings possible through use of a charted high altitude RNAV structure and 2D RNAV SIDs and STARs in six major terminal areas were derived in a previous study [12] for air carrier jet aircraft. The current study expanded the savings estimate to include a low altitude charted RNAV structure, the effects of weather routes in the high altitude structure, 2D and 3D RNAV benefits at sixty major airports, and the savings which could be realized with 4D time control navigation in twenty-five M & S terminals. Savings were estimated for air carrier, business, and other general aviation aircraft, although 3D and 4D savings were estimated only for air carrier aircraft.

The average enroute route length savings over VOR were estimated to be 2.36% for a charted low altitude structure and 1.61% for a charted high altitude structure. The high altitude structure savings include the effect of weather routes and assumes that no restricted areas will be violated. Enroute benefits are those that may be expected by an aircraft at random in a fully developed charted RNAV structure, but they are also indicative of the savings that may be expected on individual RNAV routes as they are implemented in the transition phases. The results are somewhat conservative in that the NAFEC structure upon which they are based is not an optimum coordinated structure. Terminal area 2D RNAV savings are a result of shorter route lengths for piston aircraft, and of both shorter route lengths and better altitude profiles for jet and turbo-prop aircraft. The 2D RNAV benefits include the savings due to improved climb profiles in vertical departure envelopes which generally allow each aircraft to select an optimum climb schedule. High performance climb envelopes are utilized where the limiting of the use of the route to aircraft of a certain minimum performance capability will result in shorter departure routes for such aircraft.

3D benefits are realized through pilot selection of 3D descent profiles as compared with procedural or "rule of the thumb" descent procedures. It was determined through real time simulation [11] that pilot selection of 3D descent profiles has no impact on controller workload or other ATC system benefits. Additional 4D savings in M & S terminals were derived, based on a capacity and delay analysis for 8 major airports which was extrapolated to 25 M & S airports.

Terminal area benefits, demonstrated by the results of real time simulations, also include a significant decrease in arrival holding delays, a decrease in time and distance flown, and in pilot communications workload.

Annual savings for calendar year 1984 are summarized in Table 1.1. The annual savings were computed on the basis of fuel cost plus the flight time sensitive portion of direct operating cost and did not consider the worth of

executive time in business aircraft operations. This factor can be particularly significant for business aircraft operations in which the "Value Added" concept of the worth of executive time is used and executive time savings may be valued as high as $40 per minute.

The savings summarized in Table 1.1 are applicable to an all-RNAV environment in 1984. The realization of benefits by individual users, however, is not dependent upon an all-RNAV environment. Based on an assumed implementation scenario, which is described in Section 5.1.5, it was estimated that aggregate user savings would grow almost linearly over a seven year implementation period in reaching the levels indicated in Table 1.1. In a related study [14], where costs and benefits were computed for this implementation scenario at their present (discounted) value, it was determined that the user benefit to cost ratio for the period of 1982 to 2000 would be in a range of 5.5 to 7.1.

TABLE 1.1 Summary of 1984 Annual RNAV Savings over VOR

	Total 1984 Annual Savings in Millions of 1975 Dollars							
	Air Carrier			Business			Other General Aviation	Total
	Aircraft	Passenger Time	Total	Aircraft	Pass.-Time	Total		
2D-60 Major Airports	91.1	93.5	184.6	.6	.9	1.5	1.2	187.3
3D Descents - 60 Major Airports	49.1	45.8	94.9	*	*	*	*	94.9
4D at 25 M & S Terminals	110.4	142.1	252.5	*	*	*	*	252.5
Terminal Area Total	250.6	281.4	532.0	.6	.9	1.5	1.2	534.7
Charted Enroute	98.3	95.9	194.2	1.9	2.2	4.1	3.1	201.4
Direct Enroute	119.1	116.2	235.3	2.3	2.7	5.0	5.5	245.8
Total Charted and Terminal	348.9	377.3	726.2	2.5	3.1	5.6	4.3	736.1
Total Direct and Terminal	369.7	397.6	767.3	2.9	3.6	6.5	6.7	780.5

* Not estimated

Of at least equal importance to the dollar savings with RNAV are the fuel savings which are contained therein. A summary of annual fuel savings at 1984 traffic levels is given in Table 1.2 for an all-RNAV environment.

Table 1.2 Summary of 1984 Annual RNAV Fuel Savings Over VOR

	Fuel Savings in Millions of Gallons			
	Air Carrier	Business Aircraft	Other General Aviation	Total
Terminal Area-2D	156	1	1	158
3D Descents	76	*	*	76
4D in M & S Terminals	153	*	*	153
Terminal area total	385	1	1	387
Enroute charted	171	2	4	177
Enroute Direct	208	3	7	218
Total with charted	556	3	5	564
Total with direct	593	4	8	605

*not estimated

Analysis of existing RNAV approaches indicates that a reduction in minimum descent altitude may be possible in some cases for an RNAV approach compared with a VOR approach, but that the primary advantages of RNAV (during approach) lie in the elimination of circling approaches, and in providing approaches to non-instrumented runways. In addition to the increased safety element in the elimination of circling approaches, considerable distance savings are also possible. In non-radar terminals an RNAV approach may save as much as 30 miles over a VOR approach, depending upon location of the initial approach fix with respect to the arrival waypoint. RNAV also provides the potential for application of noise abatement procedures under IFR conditions.

Projected payback for a user is dependent upon both the cost of RNAV installation and the specific savings unique to his type of operation. The benefits available to the approximately 3100 air carrier jet aircraft in 1984 would support an average amortization or payback on the order of $113,000 per year per aircraft in a total RNAV environment. This average payback is derived by dividing the total annual airline savings by the number of airline aircraft. Individual per aircraft payback, which is not dependent upon a total RNAV environment, will vary over an approximate range of $20,000 to $150,000 per aircraft per year depending upon type of aircraft and schedule. The individual aircraft benefits were derived from an analysis of six airlines' current operations.

It was determined that, if the RNAV TCA concept described in this report were chosen, 11,000 of the projected 67,000 business aircraft in 1984 and only 7,500 of the projected 145,000 non-business general aviation aircraft in 1984 would be required to have RNAV. Business and other general aviation jet and turboprop aircraft would realize an annual savings of $5850 and $2070 per aircraft respectively, based on fuel and aircraft time alone, which would yield a reasonable payback period for the cost of airborne equipment. A reasonable payback period cannot be projected for small piston aircraft on the same basis. However, as evidenced by the current popularity of RNAV equipment among general aviation users (over 4500 equipped), there are other benefits available, such as VFR pilotage aid, elimination of circling approaches, and access to airports which do not currently have a VOR approach.

The potential cost impact on military operations and equipment requirements which would be caused by the implementation of an all-RNAV environment varies widely among the services. The impact on the Coast Guard would be nominal since all USCG aircraft have relatively sophisticated multi-sensor navigation systems. The impact on the Army would depend greatly upon the way in which terminal areas are defined for purposes of requiring RNAV capability. If the RNAV TCA concept were chosen, whereby RNAV were required in airspace defined in a manner similar to current terminal control areas, only 3-5% of Army aircraft would be required to have RNAV.

The impact on the Navy and Air Force could be considerably greater. Only a small percentage of their aircraft have tactical navigation systems which could be adapted for RNAV use and little spare space exists to accommodate the installation of an RNAV computer. Many tactical aircraft are only occasional users of the National Airspace System and therefore would accrue the benefits of RNAV at a slower rate than the constant users. New aircraft system designs could probably accommodate an RNAV capability with minimal impact, but a large scale retrofit requirement could probably be fulfilled only through new and innovative equipment design.

1.4 SYSTEM RELATED RESULTS

The cost impact of RNAV on the ATC system and the benefits derived therefrom are as closely related to the operational concept which is implemented as are the corresponding costs and benefits for the users. The system impact which is presented in this report, as is the user impact, is based on the implementation of the system design concept described herein. This impact is specifically related to an RNAV environment which is achieved through an orderly evolution, based on user demand, throughout the transition phases of mixed VOR/RNAV operations.

The most important step in this evolutionary process is the development of optimum, coordinated high altitude, low altitude, terminal, and transition structures from which individual routes can be implemented throughout the transition periods. An analysis was made of route development requirements

and their impact on various elements of the ATC system as discussed below. Close coordination will be required between various services of the FAA and user groups in both the initial development of the optimum route structures and in the continuing process of implementation.

In a previous analysis [12] it was determined that the pre-1982 VORTAC coverage for the charted high altitude structure could be attained with the addition of one station, and that the post-1982 total CONUS direct coverage could be attained for $14 million plus approximately $1 million per year maintenance costs - - these estimates were based on the assumption that all VORTACs for which Task Force postulated accuracies were required had already been upgraded to achieve that accuracy, and that the Task Force recommended route width of ±2.5 nm would be required. Subsequent analysis has resulted in the conclusion that constant ±4 nm route widths will adequately accommodate expected traffic. An analysis of VORTAC coverage cost based on a ± 4 nm route width and an optimum mix of upgrading existing stations and adding new stations resulted in initial costs of $600,000 for a 1977 charted high altitude structure and approximately $6 million for the post-1982 complete CONUS coverage. These costs are nominal when compared with the annual F & E budget plan for Navigation Aids upgrading and expansion for the VOR airways system. Also, these costs are based on an overall estimate and do not reflect the requirements for the specific route structure to be implemented, nor do they consider annual maintenance savings achievable through removal of redundant stations. It can be expected that a number of stations will no longer be required, and that the annual maintenance savings would provide an early offset for any upgrading costs for RNAV coverage requirements.

The effects of slant range error were found to be negligible, from an airspace planning viewpoint, below 12,500 ft AGL in the terminal area and low altitude enroute structure. It was determined that the number of VORTACs required to support RNAV terminal areas over the CONUS was 48 less than the number required to support VOR terminal areas at the projected 1982 traffic levels. The resultant savings were estimated as $2.3 million per year due to maintenance costs associated with the VORTACs which were removed.

Preliminary estimates of the impact of RNAV on ATC automation were derived. A total of six areas in ATC automation which were determined to exhibit potential for impact were analyzed: enroute and terminal area route definition, enroute and terminal area conflict prediction, terminal metering and spacing, and enroute flow control. For the most part the impact was found to be minimal or even favorable. It was determined that the cost of enroute and terminal computer system core requirements due to the implementation of RNAV is $258,000 to support a mixed VOR/RNAV environment. However, core requirements for an all-RNAV environment would be $174,000 less than the current requirement.

A major concern of the RNAV Task Force was the possibility of penalties to the ATC system resulting during the transition period when a mix of VOR and RNAV traffic would be required. The results of real time simulations [11,12] indicated that controllers are capable of operating in a mixed VOR/RNAV environment with reduced workload and increased productivity. An increase in operation rates and decreased time and distance flown by RNAV aircraft in the terminal

area was also demonstrated. Furthermore, an increase in system capacity was evident which resulted in a significant reduction in arrival holding delays. A continuing controller training program will be necessary to insure a level of familiarity with RNAV procedures and capabilities that will result in a timely and orderly evolution to an all-RNAV environment.

RNAV will increase airspace capacity by providing a more ordered route structure, which reduces the potential for conflicts in the enroute environment. The use of 4D in M & S terminals will also provide a significant increase in capacity. A summary of the impact of RNAV on the ATC system over the period of 1982-2000 is given in Table 1.3.

Table 1.3
ATC System Impact Summary

	1982-2000			
	Savings		Costs	
	Total	Present Value	Total	Present Value
VORTAC REQUIREMENTS				
Terminal area (maintenance)	$36.1M	$8.0M		
Enroute (implementation and maintenance)			$2.4M	$0.8M
CONTROLLER PRODUCTIVITY				
Terminal Area	$26.4M	$8.0M		
Enroute	$422.0M	$120.7M		
IMPLEMENTATION (Training, automation, charting and flight inspection, route development)			$19.8M	$13.0M
TOTAL	$484.5M	$136.7M	$22.2M	$13.8M

1.5 RNAV OPERATIONAL CONCEPT

Certain modifications, expansions and clarifications of the Task Force operational concepts, which are based on the results of studies to date are summarized below.

Terminal Area Concept

2D SIDs and STARs with a route width of ± 2nm or ± 4 nm depending upon distance from the VORTAC [15] should be established at all radar terminals which overlie, and are compatible with, optimum radar vector paths in order to allow controllers and users to accrue immediate benefits and to gain experience with RNAV procedures in a manner which is compatible with radar vector procedures during

the transition period to an all-RNAV environment. The all-RNAV terminal area designs for the 1982 period should be based on a modified Task Force Design with the terminal maneuvering area aligned according to runway usage and the terminal transition area aligned according to the traffic flow. The octant concept should be relaxed as appropriate to accommodate traffic flow and to optimize the interface with the enroute structure. Slant range correction will not be required below 12,500 feet.

3D capability should not be required in the terminal area, but terminal route design should accommodate 3D separation requirements in order that 3D equipped aircraft could utilize individually selected 3D profiles within the vertical envelope provided in the 2D route design.

VNAV

The ability to utilize pilot-defined vertical routes on an ad hoc basis can provide significant economic benefits to an individual user and terminal area routes should be designed to accommodate pilot selection of 3D climbs and descents. The use of fixed gradient VNAV routes for procedural separation and/or the requiring of 3D capability for entry into certain airspace does not appear to offer sufficient payoff in either airspace capacity or operational utility to warrant serious consideration and would impose a penalty on the user. A fixed-gradient VNAV design would provide a rigid structure which would reduce the controller's flexibility for impromptu changes and which would greatly complicate the controller's visualization of the traffic picture and his ability to monitor traffic.

High Altitude Route Structure

The Task Force recommended constant ±4nm route width for the 1977 system is achievable, with the current ground station accuracy. The expected capacity of the 1980s can also be served by constant ±4 nm route widths.

The airborne equipment and FTE requirements stated in the Task Force Report are required, but VORTAC upgrading and installation cost is minimized. Slant range correction is required in the high altitude structure. The implementation of the RNAV Task Force pre-planned direct concept would require ATC automation features not yet developed, and would require a significant amount of flight checking of VORTACs to develop area coverage plots. Pre-planned direct routes will require radar monitoring until these requirements are fullfilled. The 1000 ft. vertical separation recommended by the Task Force is achievable with the altimetry improvements postulated, but only in level flight. VNAV separation is dependent upon along track error and 1000 foot separation is not generally achievable with the anticipated lateral accuracies.

Low Altitude Structure

Slant range correction should be required above 12,500 feet MSL. Aircraft operating above this altitude are required to have encoding altimeters, which is the major cost element in providing slant range correction. Slant range errors are negligible from a route design viewpoint below 8000 ft. AGL,

but a slight expansion of route width in the vicinity of the VORTAC is required from 8000 to 12500 ft. AGL. The low altitude structure should be a dual system with charted RNAV optimized and skeletal VOR structure accommodated. Pre-planned direct in the low altitude structure is dependent upon the same development features as in the high altitude structure.

Waypoint Designation

The RNAV concept involves both charted and pre-planned direct routes whose segments or, in some cases, the entire route are great circles. A variety of navigation sensors, ranging from VORTAC, to self-contained, to long range aids will be utilized. RNAV systems will range in complexity from single waypoint rho/theta analog computers to sophisticated digital multi-sensor dead reckoning systems. The charting of waypoints and the definition of impromptu waypoints, along with simplified waypoint descriptors, is necessary for the optimum use of these routes by pilots with the total range of airborne equipment. The optimum designation system is the combination of the radial/distance and pronounceable 5 alpha systems in use today.

Accuracy Tolerances

Route widths required to support airspace capacity requirements in the 1980's are not as stringent as envisioned by the Task Force, and the resulting route structure can be supported with upgrading the accuracy of only a few VOR stations. However, additional analysis of existing and planned data is necessary to completely resolve the issue of error budgeting and compliance with accuracy requirements.

RNAV Functional Requirements

The pre-RNAV Task Force operational elements necessary to provide area navigation capability were documented in RTCA publications [16,17]. The Task Force, however, detailed several additional functional requirements which are advantageous to the RNAV user and/or are required by the RNAV system operational concept, but which require additional airborne equipment capabilities. For controllers to effectively use RNAV, all operations based on like commands should result in like maneuvering of the aircraft over the ground. The basic functional capabilities issues - some as yet unresolved - are as follows:

1) Waypoint Storage - A minimum storage of more than one waypoint is required for high density terminal area operation. A method of readily and unambiguously checking waypoint storage data is required.

2) Turn anticipation requirements can probably be met procedurally, but some method of turn alert may be required.

3) RNAV systems should have the capability of parallel offsets in increments of one nm to a distance of 20 nm. Displaced needle CDI indications are not an acceptable method of parallel offset. Constant radius turns are not required, and paralleling through turns, when required, may be accomplished procedurally. The use of offsets inside a turn should be minimized.

4) When vertical guidance equipment is utilized, vertical maneuver anticipation of some type will be required. The anticipation requirement may be able to be accomplished procedurally in combination with an altitude alert signal.

5) The utilization of offsets during climb or descent, particularly when performed around a turn or in the vicinity of a crossing route turn point, should be based on a prior recognition of airspace limitations in order to insure that adequate vertical separation is maintained and that aircraft performance limits are not exceeded. When climbing or descending offsets around turns are utilized, turns may be handled procedurally in the plane of the parent route vertical path angle, or turn points may be computed on the bisector of the turn angle.

1.6 IMPLEMENTATION REQUIREMENTS

The successful implementation of Area Navigation requires a carefully coordinated, time phased, systems approach. It is particularly important that the design of RNAV structures for high altitude, low altitude, terminal and transition areas be closely coordinated. Optimum designs should be created to handle all high altitude and the majority of low altitude traffic. 2D RNAV routes which incorporate 3D altitude separation criteria should be designed for all high density and selected medium density terminals to maximize user benefits. Specific routes should be implemented from these designs (enroute and terminal) as public use routes in accordance with user requirements. Flight checking of routes should proceed in accordance with user requirements, but provisions should be made for the development of flight checked area coverage charts which will define areas and NAVAID coverage within which pre-planned direct route may eventually be utilized without radar monitoring. A three phase implementation program, similar to that recommended by the Task Force, is required, but the timing of the phases should be based on user demand.

High Altitude Enroute

In Phase 1, VOR routes should be realigned as required as RNAV routes are implemented. Limited pre-planned direct flight will be accommodated, with radar monitoring, and pilot selection of 3D descents may be utilized where not in conflict with procedural descent requirements. Tactical use of parallel offsets by RNAV equipped aircraft should be initiated. In Phase 2, 2D RNAV utilizing the charted high altitude structure will be the system, and all VOR routes will be deleted. Procedures should be established to allow wider latitude in pilot selection of 3D descents. In Phase 3, the charted RNAV structure will be retained as the system, but completion of flight checking and implementation of automation improvements will permit widespread use of pre-planned direct flight without the requirement for radar monitoring. Use of VORTACs or existing waypoints will be required for pre-planned direct flight segments by station-referenced (non-geographic) systems and will normally be used by all aircraft unless a distinct user advantage is apparent.

Low Altitude Enroute

Implementation in Phase 1 should follow the same procedures outlined for the high altitude structure. In Phase 2, unnecessary VOR airways should be deleted, and the remaining VOR airways should be realigned to conform to RNAV routes to the extent practicable. Procedures should be developed to allow pilot selection of 3D descents. In Phase 3, 2D charted RNAV with a scaled down VOR airway structure will be the navigation system. Pre-planned direct may be utilized, with station referenced (non-geographic) systems using existing waypoints or VORTACs. Radar monitoring will be required where flight checking has not been completed.

Terminal Area

In Phase 1, 2D RNAV routes should be designed for all high and selected medium density terminals. 2D SIDs/STARs should be implemented in conjunction with corresponding enroute segments, and VOR/vector paths should be realigned to accommodate RNAV routes as practicable, or the RNAV routes may be realigned if necessary. 2D SIDs should be implemented to permit pilot selection of 3D user beneficial descents. 4D procedures should be established in M & S terminals. 2D/3D approaches should be established at all airports to the extent practicable, consistent with IFR requirements. In Phase 2, 2D RNAV routes should be designed for all low density and non-radar terminals. As RNAV routes are implemented, VOR/vector routes should be realigned as necessary to conform to the RNAV routes. 2D RNAV is the navigation system in high density terminals. Climb envelopes should be established to provide shorter departure routes for high performance aircraft. In Phase 3, RNAV will become the system in medium density terminals.

1.7 CONCLUSIONS

The results obtained from economic and operational impact analyses, and from various supporting system studies, indicate that the advantages of area navigation to both the users and the ATC system are sufficient to warrant implementation of the area navigation concept described in this report. This concept is based on the Task Force recommendations, but is modified as appropriate to insure that maximum benefits will accrue to both the system and the users. Although additional research and development work is still required in some areas, implementation of the area navigation concept can proceed in parallel with these efforts.

2.0 STUDY APPROACH

The overall objectives of this analysis of area navigation payoffs and development of operational concepts and implementation requirements were (1) to review and analyze the results of previous Task Force payoff studies and supporting system studies, (2) to update and complete payoff analyses which were initiated in previous study efforts, (3) to summarize RNAV payoffs and economic impact with respect to both the ATC system and the users of the National Airspace System, and (4) to develop an operational and implementation concept, based on the RNAV Task Force recommendations, which is most beneficial to the ATC system and a broad spectrum of users.

The FAA/Industry Task Force Report [1] described an area navigation system design concept which was based on certain assumptions concerning the application and capabilities of area navigation and the requirements of the Air Traffic Control System. The Task Force recognized that a significant amount of investigative work remained to be done in order to validate the recommended operational concept and the assumptions inherent in its design. The Task Force Report listed several problems associated with the implementation of area navigation, discussed regulatory, equipment, and system requirements, and described the research and development efforts which should be accomplished prior to implementation.

The Systems Research and Development Service (SRDS) of the FAA developed an Engineering and Development Plan [18] in response to the Action Plan detailed by the Task Force, and instituted a program of system studies and analyses in the areas of RNAV Payoff, RNAV Terminal Design, RNAV Enroute Design, RNAV avionics and other supporting studies. The area indicated as that of the highest priority by the Task Force was RNAV Payoff, and the other studies were designed to provide inputs to the payoff studies.

This report contains the results of a study effort to define the costs and to assess the economic impact which are expected to accrue to the ATC system and the various users of the National Airspace System as a result of the implementation of area navigation, and to develop an operational concept for area navigation which is based on the Task Force concept, but which utilizes the results of the subsequent analyses which were recommended by the Task Force.

This section is divided into two major parts: Section 2.1 - Supporting System Studies, and Section 2.2 - Expanded Payoff Analysis. The objectives and the overall approach used in previous and ongoing systems analyses, directed at identification and solution of potential RNAV implementation problems, are summarized in Section 2.1. The study approach utilized in the expansion of previous payoff analyses and the identification of payoff and the operational and economic impact of RNAV implementation on the user and the ATC system is described in Section 2.2.

The objectives, detailed methodologies, and results of the expanded payoff analyses are given in Section 3 (User Impact) and Section 4 (System Impact).

Section 5 presents first a summary and aggregation of RNAV payoffs to the user and the system (Sections 5.1 and 5.2), then a system design concept based on these payoffs as well as the Task Force concept and results of the supporting

systems analyses described in Section 2.1 (Section 5.3), and finally a detailing of the action required for the implementation of this system concept (Section 5.4). Conclusions concerning RNAV payoff, cost impact, system design concept, and implementation requirements are given in Section 6.0.

2.1 SUPPORTING SYSTEMS STUDIES

The objectives and overall study approach utilized in the several supporting system studies are summarized in the following paragraphs. Detailed methodologies and results are presented in separate reports which are referenced in the following discussion. A summary of these results is contained in the development of the RNAV system design concept in Section 5.3.

2.1.1 Waypoint Designation Standards

The RNAV concept involves both charted and preplanned direct routes and the utilization of both earth referenced (lat-long) and station referenced (rho-theta) airborne systems. The Task Force recognized the necessity for establishing a system of waypoint location, identification, and communication which would provide for optimum use of RNAV routes by either type of system while at the same time minimizing controller and pilot workload.

Reference 3 reports the results of a study which developed recommended waypoint designation standards. The basic objectives of the study were to evaluate Task Force operational and procedural concepts and their impact on waypoint designation, to evaluate the advantages and disadvantages of grid and other alternative systems, and to develop a set of waypoint designation standards that will:

1. Present a communicable, easily remembered identifier of a unique geographical location for charting purposes for pilots and controllers.

2. Provide an identifier compatible with computer input requirements for airborne navigation, flight planning, and ground based ATC systems.

3. Apply to earth oriented as well as station oriented navigation systems.

4. Provide an easily identified and transmitted navigation fix which can be utilized in the ATC system for controller/pilot voice communications.

5. Provide the most practical means for pilots and controllers to exchange information on impromptu waypoint locations for both station referenced and earth referenced RNAV equipped users.

6. Provide a set of waypoint location and identification standards for utilization during all three RNAV implementation phases.

The approach taken in this analysis was based on satisfying, to the extent possible, the requirements for all applications of the designators. There are several basic characteristics which a designator should satisfy:

(1) Airspace Utilization (4) Charting Considerations

(2) Communicability (5) Workload

(3) Orientation Information (6) Equipment Implications

The precise specification of the desired waypoint designator characteristics produced a list of 32 designation criteria necessary to adequately satisfy the needs of the six basic characteristics. The waypoint designation criteria developed considered all phases of RNAV implementation.

The proposed waypoint designation techniques described and analyzed in this study included:

GRID SYSTEMS	NON-GRID SYSTEMS
Coded Lat/Lon	Postal Code
Radix Lat/Lon	Mnemonic 5 Alpha
Delta Distance	Pronounceable 5 Alpha
Clock Grid	VORTAC Referenced
Cardinal Radial	Arrival/Departure
Radial Distance	Standardized Location Designation
Computer Generated	5 Numeric Designator

The preferred designation symbology derived from this analysis was a dual designator consisting of a combination of a grid and non-grid designation system. The recommended combination is the Radial Distance (polar grid) designator, and the Pronounceable 5 Alpha (non-grid) designator which are in use today for area navigation. The investigation failed to reveal any new technique which would be more advantageous. While certain other technqiues are superior with respect to one or more of the criteria, the system chosen ranked highest in overall acceptability. In addition to the recommendation for waypoint designation, corresponding standards were developed in the following areas:

(1) Facility Selection for RNAV Routes
(2) Parallel Offset Considerations
(3) Waypoint Charting
(4) Waypoint Location and Route Definition

2.1.2 Avionics Standards

RNAV equipment functional and accuracy requirements to provide area navigation capability were documented in RTCA publications [16,17] and in Advisory Circular 90-45A [19]. The Task Force developed additional concepts which may be advantageous to the user and/or are required by the system operational concept, but which require additional functional capabilities. The Task Force also recommended system error budgets which are based on the RSS method of combining errors and which postulate an improvement in flight technical error over that currently attained. A need existed to validate, through flight test and simulation, the assumptions inherent in the Task Force Concept, and to develop a set of Avionics Standards and Minimum Operational Characteristics which are based on an operational concept more closely aligned to that recommended by the Task Force.

An avionics standards program was undertaken which included a series of flight tests and simulations designed to provide the data base necessary to resolve the issues raised by the Task Force concept. The basic method of approach for this study was to examine existing area navigation functional and accuracy requirements, to compare this set of information with the concepts described in the RNAV Task Force Report, and then to develop and categorize the minimum operational characteristics regarded as necessary for acceptable performance within the National Airspace System.

Flight tests were conducted using a variety of area navigation systems, from a single waypoint analog system to an ARINC-582 system, in aircraft ranging from an Aero Commander 500 to a DC-10. The flight tests were supplemented by simulations using GAT-II cockpit simulators. An interim report [7] which summarizes the form and substance desired for an updated avionics standards document has been prepared.

The standards developed were categorized into Basic Design Considerations, Standard Functional Requirements and Unresolved Equipment Capabilities. There were five unresolved issues solely related to 2D area navigation and two additional issues related to 3D area navigation.

Unresolved Equipment Capabilities

2D Only	Additional 3D Considerations
(1) Waypoint Storage	(1) Vertical Maneuver Anticipation
(2) Turn Anticipation	(2) Parallel Descent Maneuvers
(3) Parallel Offset	
(4) Track Determination	
(5) Slant Range Error	

Ongoing analysis of flight test and simulation data, coupled with consideration of equipment cost versus user and benefit, is designed to resolve these issues. The issues of system error budgets, error combination techniques and flight technical error are also undergoing additional analysis. The analysis of slant range error initiated in Reference 7 was expanded and is included in Section 4.1 of this report.

Preliminary conclusions concerning the unresolved issues have been made, based on analysis to date, wherever they have a bearing on the development of a recommended RNAV system design concept.

2.1.3 Terminal Area Design

The RNAV Task Force recommended a time-phased implementation of RNAV, and provided for two transition periods in which terminal area designs would be based on compromises between the post-1982 RNAV concept and the requirement for retaining VOR routes. The Task Force report contained a terminal area model providing for alternating arrival/departure octants, a final approach terminal maneuvering area, and specifying the location of arrival and departure waypoints.

A terminal area design and analysis program was initiated to validate the Task Force concepts.

The basic objectives of the program were twofold:

(1) Evaluate the RNAV and VNAV (3D) Task Force terminal area design concept by applying it to various medium and high density terminal areas

(2) Based on an analysis of the terminal area designs, recommend design techniques to be used in the pre-1977 and 1977-82 transition periods, and in the post-1982 period, for the development of both 2D and 3D RNAV terminal area designs

The major source of data and information on present terminal area designs was furnished by ATC teams from the National Aviation Facilities Experimental Center (NAFEC) who visited 14 terminal areas and collected all available information. This information was used to develop the current radar vector and VOR traffic flow patterns used in the terminal areas for both primary and satellite IFR airports.

The Task Force 2D RNAV terminal model was applied to seven terminal areas (13 airports). Preliminary time phased designs were created at all seven terminal areas. The first time period designs, pre-1977, were based heavily upon current terminal area procedures. RNAV routes in this time period often were essentially coincident with current radar vector and VOR routes. The second time period designs, 1977-82, were based upon accommodating both RNAV and VOR aircraft. The Task Force design was used to the maximum extent possible under the constraint of maintaining a satisfactory VOR traffic flow utilizing current navigation facilities at their present locations. The third time period design, post-1982, made use of the Task Force terminal area model to the maximum extent possible based upon the constraints of the characteristics of the terminal area.

The sequence of design development began with the design of the pre-1977 RNAV routes based on the present VOR route structure. Then the post-1982 RNAV routes were developed and the design effort for each terminal area concluded with the development of the mixed RNAV-VOR route structure for the 1977-1982 time period. The major perturbing factors in the application of the Task Force design to post-1982 designs were caused by multiple major airports in the terminal area and by complex runway layouts which necessitated modification of the terminal routes that were near the airport.

Terminal RNAV routes were developed for the following terminal areas for all three time periods: New York (LGA, JFK, EWR), Denver, Philadelphia, Chicago (ORD, MDW), New Orleans, San Francisco, and Miami. The 1972-1977 and post-1982 designs also included FLL, OAK, and SJC.

Two New York terminal transition period designs furnished the basis for a comprehensive real time simulation effort at NAFEC [9]. The simulation was designed to determine the controller's ability to operate in a mixed VOR RNAV environment during the transition period. Data on the impact of RNAV on the user and on controllers' workload were also recorded.

Nine airports in all seven designs (FLL, OAK, SJC, and MDW were excluded) were subjected to an analysis of route length and altitude restriction effects upon four types of turbojet aircraft. Economic comparisons were made between the post-1982 route structures and the current radar vector/VOR route structure.

The results of these analyses tended to point out apparent weaknesses in some elements of the Task Force terminal design model. In order to correct these weaknesses a modified Task Force terminal design procedure was developed. This procedure called for a greater use of the traffic density and direction of traffic flow information for the terminal area. In addition, the design of vertical departure route profiles for both 2D and 3D equipped aircraft which could accommodate varying aircraft climb performance was used. The arrival route vertical profiles were designed to maximize user benefits through pilot selected 3D descents. This design procedure was applied to the New York terminal area and the resulting design was also subjected to the route length and altitude restriction analysis program. The results of this analysis indicated that a considerable improvement in user benefits (time and fuel) could be expected if such a design were applied to the New York area operations as well as other areas. Selected high performance departure routes were developed for New York as well. These routes were developed in places where shorter route lengths to the boundary of the terminal area could be achieved if a minimum gradient can be attained by the aircraft using the route. Analysis of this design concept indicated that high performance departure envelopes provide a definite benefit to the user. Both time and fuel savings were achieved by aircraft using the envelopes rather than the corresponding RNAV route.

The terminal area designs were reviewed with Air Traffic Service personnel at the appropriate regions. New terminal area designs were then performed, based on both the region comments and considerations of the user related route length and altitude restriction economic analysis, and revised terminal area design guidelines were developed. The analysis also included determination of the incremental benefit realized through pilot selection of 3D descents. The new terminal area designs were subjected to the route length and altitude restriction analysis in an iterative procedure designed to optimize the designs for user economics, as reported in Section 3.1 of this report.

The new post-1982 terminal area design was utilized as the basis for a second real time simulation effort at NAFEC [11]. This simulation was designed to gather additional data on the controller's ability to operate in a mixed VOR/RNAV environment, to evaluate the impact of various levels of RNAV, VNAV, and radar-vectored traffic on system performance and the efficiency of operation of the system user, and to explore the effectiveness of vertically layered ("stacked") arrival routes. The simulation included the utilization of wind and navigation system error models.

2.1.4 Route Width Requirements

The RNAV Task Force report developed system accuracy requirements based on the assumption that route widths would have to be progressively reduced to ±1.5 nm in the terminal area in order to accommodate traffic demand in the 1980s. Several analyses have subsequently been performed which addressed specifically the route widths required to meet the needs of forecasted traffic in an RNAV environment.

The requirement for route widths to satisfy traffic demand and the impact of route width on route design were addressed in three separate studies.

In one study [5], the objective was to quantify the current effective route width and the limitations which it imposes upon other aspects of the airway system, and to determine the requirements for reduced route widths. Route width was found to have an effect on the adequacy and interaction of route location, on the ability of the route structure to provide the required number of routes, and on route length. The impact on each of these areas was quantified through analysis and simulation and it was determined that traffic demand could be accommodated with constant ± 4 nm route widths.

The impact of route width was also considered in the terminal area design process described in Section 2.1.3 and in the development of the high altitude route structure described in Reference 4, and the acceptability of ± 2 nm and ± 4 nm route widths respectively was verified.

2.2 EXPANDED PAYOFF ANALYSIS

The economic impact of area navigation on the ATC system and the users, as reported in References 11 and 12 and updated and expanded in Sections 3 and 4 of this report, was assessed as described in the following sections.

2.2.1 Terminal Area Analysis

The results of a route length and altitude restriction analysis of seven preliminary terminal area designs covering nine airports were presented in Reference 12. These results compared preliminary post-1982 designs with current VOR/radar vector routes, and quantified the savings in time and fuel available for several levels and projected mixes of traffic. These results, together with operational inputs from the appropriate FAA regions, were then used to develop new terminal area designs. The new terminal area designs [2] were subjected to the route length and altitude restriction analysis (described in Section 3.1) and the results of this analysis were extrapolated to a national scale, and further presented in terms of annual dollar savings in Section 5.1.3.

2.2.2 Enroute Impact Analysis

In the previous analysis [12] route length savings and conflict effects were computed for both high altitude charted RNAV, based on a 184 airport pair structure, and a high altitude direct structure, compared with the current VOR high altitude structure. Subsequently, an expanded high altitude structure was developed [4] and analyzed for route length and conflict effects. The results of this analyses are described in Section 5.1.2. The no-wind route length analysis of the high altitude structure was calibrated by a simulation and analysis of RNAV weather routes compared with existing VOR weather routes. This analysis is described in Section 3.2. Also, an analysis of low altitude enroute route length effects was performed as described in Section 3.3. The fuel and time savings due to all enroute route length effects are summarized in Section 5.1.2. Additionally, a discussion of the impact of more desirable altitude assignments in an RNAV environment is included in Section 5.1.2.

2.2.3 User Group Analysis

Previous payoff studies [12,13] were limited to the fuel and time effects of RNAV on air carrier jet aircraft operations. The current analysis expanded that effort in several areas. The terminal area and enroute impact analyses, described in Sections 2.2.1 and 2.2.2 above, included a broader spectrum of aircraft types, and estimates were made of dollar savings applied to business jet and other general aviation operations. The results of this analysis is given in Section 5.1.4, and the results of the expanded airline impact analysis is given in Section 5.1.3.

A series of interviews was conducted with various user groups to determine their respective views concerning RNAV implementation and to identify cost elements associated with that implementation as well as areas of potential benefit. Interviews were conducted with representatives of the National Business Aircraft Association, Aircraft Owners and Pilots Association, Helicopter Association of America, General Aviation Manufacturers Association, U.S. Army, U.S. Air Force, U.S. Navy, and U.S. Coast Guard. The information obtained was used to identify single event benefits, to calibrate the assumptions necessary in the analysis of enroute and terminal area fuel and time benefits, and to assess the overall impact of RNAV implementation on each of the user groups. An analysis of the impact of RNAV implementation on military aircraft is contained in Section 5.1.4.4.

The benefits accruing to each user, and the expected payback, is a function of both the cost and the capability of his airborne RNAV equipment, which in turn are related. Section 3.5 presents an analysis of capability versus cost for a postulated range of equipment complexity based on currently available hardware, and the relationship of cost to expected benefits is discussed in Section 5.1.

The Task Force recommended that RNAV capability be required in all medium and high density terminal areas as well as the high altitude structure. An assessment was made of the number and type of general aviation aircraft which would be required to purchase RNAV equipment as the "price of entry" to terminal areas as a function of various methods of defining those "terminal areas". The methods of defining the terminal areas ranged from the Task Force concept of a nominal 45 nm radius to a Terminal Control Area (TCA) concept where RNAV equipment would be required for only the primary airports and closely adjacent satellite airports. The analysis also included an assessment of VOR and DME equipment requirements to interface with the airborne RNAV equipment. The results of this analysis are given in Section 3.5.2. An analysis was also conducted of RNAV approach benefits attainable both through decreased minimums and mileage saved compared with existing approaches, and the results are discussed in Section 5.1.1.4.

2.2.4 ATC Impact Analysis

Previous efforts [12,13] investigated the ability of the controller to operate in a mixed VOR/RNAV environment, estimated controller productivity increases due to RNAV, studied the effects of RNAV on enroute and terminal area capacity, and made preliminary estimates of terminal area and high altitude enroute requirements for VORTAC coverage to support an RNAV structure compared with that to support a VOR structure expanded to accommodate an equal amount of traffic.

In the current effort, the enroute high altitude VORTAC requirements analysis was expanded to include upgrading and moving of VORTAC stations as well as the addition of new stations, and a parametric analysis was performed relating coverage requirements to accuracy, station upgrading cost, relocation cost, and new installation cost. Both VOR/DME and DME/DME coverage was analyzed. Results of this analysis are given in Section 4.2.

The preliminary analysis of terminal area VORTAC requirements [12] was expanded in Section 4.3 to include a more detailed assessment of the relationship between traffic density, fix requirements, and VORTAC requirements. The analysis of the effects of slant range error which was initiated in Reference 7 was expanded through flight tests and additional analysis, and the results applied to the assessment of VORTAC requirements in the terminal area. The potential effect of slant range error on low altitude enroute structure route placement was also determined. Results are given in Section 4.1. An assessment was made of RNAV route development requirements. The initial development of optimum high altitude, low altitude and terminal area structures, from which individual routes may be implemented in an evolutionary manner, was considered. An analysis also was made of the impact of RNAV route development on the related areas of charting, ATC automation, video maps, flight checking, VORTAC requirements and RNAV approaches. This analysis is described in Section 5.4.4.

The impact of charted and preplanned direct RNAV operations on both enroute and terminal area automation requirements was investigated as described in Section 4.4. Potential impact was considered with respect to storage and computational requirements for metering and sequencing, route definition, flow control, and automatic conflict prediction and resolution. Both hardware and software impact was assessed and an overview of potential problem areas, elements of probable impact, and cost impact was prepared.

Data from the terminal area real time simulations described in References 9 and 11 and from the conflict analysis of Reference 10 were utilized to analyze the impact of RNAV on the controller and on system capacity. Controller impact is discussed in Section 5.2.2 and airspace capacity is discussed in Section 5.2.4.

An analysis of the impact of VNAV on airspace capacity is given in Section 4.5. A comparison is made of the airspace required for crossing 2D routes, with procedural separation accomplished by altitude restrictions, with the airspace required for crossing 3D routes.

2.3 SYSTEM DESIGN CONCEPT AND IMPLEMENTATION REQUIREMENTS

The results of the payoff analyses, operational and economic impact analyses, and the several related systems studies were used in conjunction with the Task Force recommendations to formulate a system design concept and implementation scenario. The recommended concept is described in Sections 5.3 and 5.4, and includes an identification of the modifications made to the Task Force recommended concept.

3.0 USER IMPACT ANALYSIS

This section addresses the impact of RNAV on several areas of user operation. Section 3.1 contains an analysis of fuel and time impact of RNAV operation in the terminal area, including both 2D RNAV and 3D descents. The sensitivity of these benefits to selection of descent procedure is also discussed. Section 3.2 presents an analysis of the effect of weather routes and restricted areas on high altitude route length savings and Section 3.3 estimates the RNAV route length savings available in the low altitude structure. The impact of 4D time control navigation on both capacity and delay is examined in Section 3.4. In Section 3.5 an analysis is made of RNAV capability versus cost of airborne equipment and finally, in Section 3.6, the RNAV savings available to six individual airlines is analyzed.

3.1 TERMINAL AREA ROUTE LENGTH AND ALTITUDE RESTRICTION ANALYSIS

In a previous analysis [12] preliminary terminal area RNAV designs for seven terminal areas (9 airports) were examined to determine the incremental fuel and transit time effects for several jet aircraft, compared with current VOR/vector procedures in the same terminal areas. The results of this analysis were reviewed by appropriate users and the FAA regional/facility offices affected. Following this review, the recommendations received were combined with the results of the user economic analysis in an iterative process to improve the designs. The design process, which is described in more detail in Section 5.3.1.2 and Reference 2, involved maximizing economic benefits on a traffic weighted basis for both 2D and 3D equipped aircraft, while providing an optimum RNAV design with respect to traffic flow, airspace capacity, and controller workload. Traffic demand data was taken from the North American Edition of the Official Airline Guide [20].

3.1.1 Analysis of Improved 2D RNAV Terminal Area Designs

An analysis of RNAV terminal area designs was performed for nine airports (JFK, LGA, EWR, MSY, MIA, PHL, ORD, DEN and SFO) in order to determine the impact of route length and altitude restrictions on direct operating cost. The incremental fuel and transit time effects were determined for several typical jet and turboprop aircraft (B-747, B-727, DC-8, DC-9, F-28, FH-227, DC-10, Lear 25C). Route length effects were determined for each terminal area in order to estimate the savings available to low altitude reciprocating engine traffic, whose fuel consumption and transit time is less dependent upon altitude than jet aircraft. The analysis compared Phase 3 (post-1982) terminal area designs with current VOR/radar vector routes. These designs are described in detail in Reference 2, and the methodology used in their evaluation is described in detail in Reference 12 and is summarized below.

Altitude restrictions imposed during climbs and descents have an immediate effect on the direct operating costs of turbine aircraft since they impact speed and fuel consumption rates. An automated model was developed for accurately evaluating the fuel and time penalties due to route length and altitude restriction effects in a given terminal area design, and for comparing competing designs in order to evaluate RNAV benefits. The analysis is based on traffic demand, and the results are traffic weighted averages of all routes in the terminal area. The aircraft climb and descent performance data used in the current analysis and the corresponding fuel and time penalty data are listed in Appendix A.

The final 2D RNAV results for each of the nine airports for which final designs were developed are listed in Table 3.1 by aircraft type and are expressed as the fuel (lb) and time (min) benefits per operation (average of arrival and departure). The benefits listed include those attained through use of departure envelopes for higher performance aircraft. The departure envelope concept provides a guidance "floor" representing a specified climb gradient above which each aircraft must operate. The guidance floor is specified by crossing altitude restrictions and may be flown by both 2D and 3D equipped aircraft. In some cases a fixed altitude "ceiling" must also be established in order to provide separation from overflying routes. The gradients defined by the floor and ceiling altitude restrictions may change as each restriction point is passed. This concept is potentially applicable to all terminal areas. However, among the nine airports analyzed, only three (EWR, JFK and LGA) designs resulted in configurations which could be improved through use of high performance departure envelopes. In the other six cases, minimum length departure routes were achieved which would accommodate all aircraft with generally unrestricted climb profiles which could not be improved by establishing a new route. The high performance departure envelopes can generally be utilized by all jet aircraft except heavy B-747s, B-707s and DC-8s.

In order to extend the RNAV terminal area benefits to terminal areas for which RNAV route designs were not developed, a regression analysis was performed. The objective of the analysis was to develop an equation in which the time and fuel benefits per terminal area operation could be computed for each of the eight aircraft types at all of the high and medium density terminal areas. Several terminal area parameters were selected as candidate estimation parameters. Several of these characteristics were related to traffic activity within the terminal area. These included:

- annual instrument operations at the primary airport
- total annual operations at the primary airport
- total annual operations at the satellite airports
- total air carrier operations at the primary airport
- total general aviation itinerant operations at the primary airport
- total itinerant operations at the primary airport

Several other characteristics were related to the existing VOR route structure. These included:

- number of VORTAC stations in the terminal area
- number of high altitude routes
- number of low altitude routes

An analysis of time and fuel benefits versus these individual characteristics of the seven designs (9 airports) yielded little correlation. However, it was determined that a good estimate for extending RNAV benefits to other terminal areas was a least squares fit of benefit versus the difference between air carrier operations and general aviation itinerant operations at the primary airport for five of the terminal areas. New York was excluded because of its singular nature insofar as terminal area complexity is concerned, and Chicago was excluded because of the extremely large number of operations at a multiple runway configured single airport. Although the remaining airports exhibit unique characteristics, summarized in Table 3.2, which make them representative

Table 3.1 2D RNAV Benefit - Improvement of 1982 TMA RNAV Design Over 1972 VOR/Vector Design

Airport	Flow		Savings per operation (average of arrival and departure) (1) (2)																
			DC-9		B-727		DC-8		B-747		DC-10		FH-227		F-28		Lear 25		AVERAGE DISTANCE SAVED
	direction	%use	Fuel (lb)	Time (min)	Fuel (lb)	Time (min)	Fuel (lb)	Time (min)	Fuel (lb)	Time (min)	Fuel (lb)	Time (min)	Fuel (lb)	Time (min)	Fuel (lb)	Time (min)	Fuel (lb)	Time (min)	
PHL	E	30	23.1	.23	32.9	.24	64.9	.25	98.5	.24	60.4	.25	9.0	.12	14.3	.20	6.6	.21	0.76
	W	70	25.[illegible]	.27	34.5	.27	55.0	.27	71.6	.26	56.0	.26	8.9	.09	14.6	.22	6.5	.24	0.67
DEN	W	80	74.4	.39	62.4	.39	75.0	.38	137.1	.35	95.2	.35	18.4	.67	27.2	.42	9.3	.40	2.34
	E	20	30.6	.13	49.4	.08	44.0	.10	32.1	.01	53.6	.08	19.3	.76	28.4	.23	9.9	.20	3.35
MSY	E	50	17.1	.22	27.5	.23	65.8	.24	130.6	.29	50.6	.25	7.0	0	12.0	.20	5.4	.17	0
	N	50	62.0	.70	91.9	.70	58.1	.71	296.4	.71	170.7	.72	29.8	.91	41.4	.73	17.5	.68	3.92
ORD	SE	50	13.8	.16	21.0	.17	35.1	.18	62.8	.18	38.7	.18	6.2	.15	10.3	.18	4.7	.17	0.66
	W	50	31.3	.33	44.8	.33	60.4	.35	90.5	.35	79.8	.36	13.3	.42	21.2	.33	8.3	.33	1.81
MIA	E	70	43.3	.46	58.7	.46	90.3	.45	127.2	.46	89.6	.45	16.9	.30	27.8	.42	12.3	.44	1.24
	W	30	67.2	.72	93.6	.72	157.3	.71	266.4	.76	101.0	.72	22.0	.40	44.6	.69	19.3	.69	2.31
SFO	W	75	82.2	.92	95.2	.93	169.4	.78	343.4	.94	195.6	.89	30.4	.96	39.0	.85	24.2	.81	4.10
	SE	25	45.8	.52	65.6	.46	46.4	.50	102.3	.44	109.2	.44	28.0	1.68	34.6	.65	9.8	.57	7.51
JFK	SW	50	249.5	2.52	243.1	2.57	564.4	2.57	959.5	2.63	607.8	2.63	105.5	2.37	170.6	2.60	76.8	2.65	9.91
	NE	50	276.3	2.86	385.2	2.82	606.1	2.81	1039.4	2.82	675.7	2.85	123.3	3.14	188.9	2.93	82.8	2.95	13.30
LGA	SW	50	309.0	3.17	455.3	3.24	732.8	3.22	1169.0	3.35	764.3	3.37	132.6	2.08	230.1	3.23	109.9	3.37	8.37
	NE	50	165.9	1.79	238.1	1.59	383.1	1.68	586.5	1.71	402.3	1.79	67.2	.67	111.0	1.45	54.5	1.56	1.60
EWR	SW	50	179.3	1.92	264.3	2.03	489.2	1.97	898.8	2.13	480.6	2.11	71.7	.80	128.5	1.92	62.1	1.97	2.99
	NE	50	92.6	1.01	135.3	1.05	254.2	1.05	461.8	1.14	230.5	1.07	33.2	.16	61.4	.88	29.1	.89	0.45

(1) The positive values indicate a benefit to the airpsace user. (2) all aircraft types do not operate at all airports shown even though data is presented for that operation

TABLE 3.2

CHARACTERISTICS OF TERMINAL AREAS ANALYZED

NEW YORK	- Complex metroplex area which has three major airports and several major satellite airfields.
CHICAGO	- Metroplex area which is dominated by one airport with a complex runway structure.
SAN FRANCISCO	- One major airport with several major satellites lined up around San Francisco Bay. Noise and terrain problems as well.
MIAMI	- No terrain problem but a very concentrated traffic area to the north. Unbalanced traffic distribution. One major satellite airfield at Fort Lauderdale.
PHILADELPHIA	- A major terminal area which lies between two metroplex areas. (New York and Washington)
DENVER	- Severe terrain problems to the west and a two directional (east-west) traffic flow.
NEW ORLEANS	- Medium density terminal area with a perpendicular runway structure and hemispherical traffic flow.

of most of the categories of large airports throughout the United States, the RNAV benefits at each was strongly correlated to the dominance of air carrier traffic over general aviation traffic. The amount of air carrier traffic is generally indicative of the amount of high altitude arrivals and departures, and the amount of general aviation traffic is generally indicative of the amount of low altitude traffic. Since fuel and time benefits are a result primarily of realignment of terminal area routes to better accommodate high altitude traffic, the correlation is not unexpected. The estimated benefits for each airport and each aircraft type are given in Table 3.3.

Table 3.3 Terminal Area Benefits (Fuel and Time Savings per Operation)

Airport	Annual 1974 Itinerant Operations-Air Carrier Minus General Aviation	B - 747				DC - 10				DC - 8				B - 727			
		Fuel - Lb.		Time-Min.		Fuel-Lb.		Time-Min.		Fuel-Lb.		Time-Min.		Fuel-Lb.		Time-Min.	
		TMA Analysis	Estimate	TMA Analysis	Estimate	TMA Analysis	Estimate	TMA Analysis	Estimate	TMA Analysis	Estimate	TMA Analysis	Estimate	TMA Analysis	Estimate	TMA Analysis	Estimate
EWR		683.9		1.63		355.6		1.59		371.7		1.51		199.8		1.54	
LGA		877.8		2.53		583.3		2.58		558.0		2.45		346.7		2.41	
JFK		999.5		2.72		641.8		2.74		585.3		2.69		364.2		2.70	
ORD		76.7		.27		59.3		.27		47.8		.27		32.9		.25	
MSY	57,000	213.5	133.4	.50	.34	110.7	82.2	.49	.35	62.0	64.7	.48	.36	59.7	51.8	.47	.35
DEN	45,000	116.1	124.4	.28	.31	86.9	77.1	.30	.32	68.8	59.4	.32	.33	59.8	49.4	.33	.32
PHL	61,000	79.7	136.4	.25	.35	57.3	83.9	.26	.36	58.0	66.5	.26	.36	34.0	52.6	.26	.36
MIA	156,000	169.0	207.5	.55	.60	93.0	124.4	.53	.58	110.4	108.2	.53	.55	69.2	71.4	.54	.60
SFO	226,000	283.1	259.8	.82	.79	174.0	154.3	.78	.75	138.6	139.0	.71	.69	87.8	85.3	.81	.77

Airport	Annual 1974 Itinerant Operations-Air Carrier Minus General Aviation	DC - 9				F - 28				Lear Jet - 25				F - 227			
		Fuel - Lb.		Time - Min		Fuel - Lb.		Time - Min.		Fuel - Lb.		Time - Min.		Fuel - Lb.		Time - Min.	
		TMA Analysis	Estimate	TMA Analysis	Estimate	TMA Analysis	Estimate	TMA Analysis	Estimate	TMA Analysis	Estimate	TMA Analysis	Estimate	TMA Analysis	Estimate	TMA Analysis	Estimate
EWR		136.0		1.46		95.0		1.40		45.6		1.43		52.5		.48	
LGA		237.5		2.48		170.6		2.34		82.2		2.46		99.9		1.28	
JFK		258.9		2.69		179.8		2.77		79.8		2.80		114.4		2.76	
ORD		22.6		.25		15.8		.26		6.5		.25		9.8		.29	
MSY	57,000	39.6	43.4	.46	.35	26.7	23.4	.47	.35	11.5	9.2	.43	.34	16.4	15.1	.45	.38
DEN	45,000	65.6	41.8	.34	.32	27.4	22.4	.38	.32	9.4	8.5	.36	.32	18.6	14.3	.69	.35
PHL	61,000	24.6	38.9	.26	.36	14.5	23.8	.21	.36	6.5	9.5	.23	.35	9.2	15.4	.10	.40
MIA	156,000	50.5	57.5	.54	.60	32.8	31.9	.50	.58	14.4	15.4	.52	.55	16.4	22.2	.33	.69
SFO	226,000	73.1	67.0	.82	.78	37.9	37.9	.80	.74	20.6	19.9	.75	.72	29.8	27.1	1.14	.90

In order to apply the benefits for each aircraft type to each airport, it was necessary to develop an estimate of the number of operations expected by each aircraft type in each terminal area in the period of interest. Calendar year 1984 was chosen as the baseline period in which to assess the benefits of an all RNAV vs all VOR environment. This year was chosen since it falls within the post-1982 implementation phase described by the Task Force and represents a reasonable estimate of the earliest date at which an all RNAV environment might be expected to exist. Estimates of the distribution of aircraft operations by type of aircraft were developed from two sources. An equipment forecast for the top 25 air carrier airports, 1975-2000, was provided by the Office of Aviation Policy of the FAA, which was generated as a part of their study of the Upgraded Third Generation ATC System. This information, together with data from Terminal Area Forecast [21], was used to develop the estimates. An estimate was made for the primary airports in each of the terminal areas defined by the Task Force as high or medium density. Only CONUS terminals were considered, and Seattle and Ft. Lauderdale-Hollywood airports were added to the Task Force list due to traffic projections. The resulting list of 60 major airports, and the estimates of the number of operations in CY1984 for each aircraft type are given in Table 3.4. Since data were not available concerning distribution of business jet operations by type, they are included as a single category in Table 3.4. Estimated business jet operations were derived as a fixed percentage of forecast general aviation itinerant operation in CY1984. Information provided by the National Business Aircraft Association (NBAA) on the number of business aircraft flights was compared with total itinerant general aviation operations from Reference 21 to develop an estimate of this percentage (4.85%). The airports in Table 3.4 are grouped according to whether they are air carrier or general aviation operation dominant.

The regression equations were used to estimate the fuel and time benefits per operation at each airport for each type of aircraft, and the total annual benefits were determined by applying the per operation benefit data to the operations listed in Table 3.4. A summary of total annual fuel and time savings at the 60 major airports studied is given in Table 3.5. The benefits for each aircraft type (B-747, DC-10, DC-8, etc.) were assumed to be representative of the benefits available to all other aircraft within the same category:

4 engine Wide Body - B-747
3 engine Wide Body - DC-10
4 engine - DC-8
3 engine - B-727
2 engine - DC-9
business jet and turboprop-Lear Jet, F-28, F-227

The business jet and turboprop category represents a weighted average benefit of the three types studied, with each of the three representing a category of aircraft to which other types were assigned. The fuel and time savings of business jets at each airport were approximated by interpolating between the savings computed for the Lear Jet and the F-28 on the basis of average maximum engine thrust. Thrust data was obtained from Reference 22, and distribution of types of aircraft was based on NBAA data. The fuel and time savings of business turboprops were approximated in the same way as a percentage of F-227 savings.

Table 3.4 Estimated 1984 Terminal Area Operations by Type of Aircraft

	AIRPORT	Number of Operations in 1984 (X1000)					
		4 Engine Wide Body	3 Engine Wide Body	4 Engine Reg. Body	3 Engine Reg. Body	2 Engine Reg. Body	Business Jets and turboprops
Air Carrier Dominant	EWR	13	45	16	99	108	4
	LGA	—	42	—	135	113	4
	JFK	71	71	43	85	64	3
	ORD	50	118	25	235	192	3
	MSY	3	24	3	64	78	2
	DEN	6	46	—	107	126	2
	PHL	8	29	11	84	132	5
	MIA	22	76	16	129	72	3
	SFO	42	76	29	155	80	1
	ATL	12	100	12	218	248	6
	BOS	18	40	15	95	117	3
	CLE	4	28	1	43	63	4
	DFW	9	56	13	209	141	6
	DTW	8	42	16	62	72	5
	IAH	6	27	8	94	57	3
	LAX	60	116	37	167	83	3
	PIT	8	20	—	61	164	4
	STL	1	31	8	88	127	5
	DCA	—	28	—	112	93	4
	BDL	—	—	7	26	47	5
	BUF	—	6	3	43	31	5
	CVG	—	—	4	28	67	4
	IND	—	—	2	18	75	6
	JAX	2	3-11	2	24	27	5
	MCI	2	9	—	99	61	1
	LOU	—	—	1	16	56	7
	MSP	9	26	—	62	54	5
	MCO	—	4	3	32	31	-
	PDX	—	2	9	73	46	4
	SMF	—	—	4	18	28	2
	TPA	3	22	3	63	23	6
	SEA	11	32	9	61	20	7
General Aviation Dominant	MEM	—	—	2	34	99	10
	PHX	—	—	17	44	67	13
	SAT	—	—	3	51	21	7
	SAN	—	9	38	70	—	7
	IAD	18	11	15	55	20	5
	BAL	—	26	6	42	36	9
	ALB	—	—	—	43	9	4
	ABQ	—	—	—	37	50	3
	BHM	—	—	—	23	24	7
	CLT	—	—	—	20	40	7
	DAY	—	—	3	18	44	7
	DSM	—	—	—	18	15	10
	ELP	—	3	1	18	20	6
	HWD	—	15	3	39	23	15
	TYS	—	—	—	7	33	5
	LAS	8	24	8	44	84	7
	MKE	1	—	2	39	47	6
	BNA	—	—	—	22	32	7
	ORF	—	—	—	33	33	4
	OKC	—	4	2	54	4	7
	OMA	—	—	—	40	19	8
	PVD	—	—	—	16	32	2
	RDU	—	—	—	12	40	7
	ROC	—	6	3	32	22	5
	SLC	—	—	3	23	71	9
	SYR	—	5	3	34	18	5
	TUL	—	2	1	36	15	8
	CMH	11	32	9	61	20	8

TABLE 3.5 2D RNAV FUEL AND TIME ANNUAL BENEFIT SUMMARY

AIRPORTS	4 Eng. W.B.		3 Eng. W.B.		4 Eng. R.B.		3 Eng. R.B.		2 Eng. R.B.		Business Jet and Turboprops	
	Fuel (1000lb)	Time (1000min)	Fuel (1000lb)	Time (1000min)	Fuel (1000lb)	Time (1000min)	Fuel (1000lb)	Time (1000min)	Fuel (1000lb)	Time (1000min)	Fuel (1000lb)	Time (1000min)
NEW YORK LGA EWR JFK	79,856	214	86,069	375	31,115	140	97,542	709	58,096	592	616	20
CHICAGO ORD	3,835	14	6,997	32	1,195	7	7,732	63	4,339	50	18	1
MSY, DEN, PHL, MIA, and SFO	17,584	51	28,608	133	6,609	33	35,612	265	24,086	213	124	5
23 AIR CARRIER DOMINANT AIRPORTS	37,172	111	99,432	390	17,102	88	129,300	1,020	153,993	979	1,034	46
28 GENERAL AVIATION DOMINANT AIRPORTS	2,250	4	5,835	21	3,402	20	31,476	115	26,738	96	675	19
TOTAL	140,697	394	226,941	951	59,423	288	301,662	2,172	267,252	1,930	2,467	91

Projected annual savings in dollars, based on the fuel and time savings described in this section, are developed in Section 5.1.1, and additional benefits which are realized through the ability of an RNAV equipped aircraft to better adhere to the desired path are also discussed.

3.1.2 VNAV Descent Analysis

Vertical navigation (VNAV) provides the capability for optimizing the point where descent should be initiated. This can be very advantageous to the user over present procedures since the point at which descent is initiated would be later than would occur otherwise. Since a given type of descent requires the same distance regardless of when it is initiated, an early descent requires that the aircraft cruise at a lower altitude until the navigation fix where the descent altitude is required to be achieved is reached. Through the use of VNAV capability, this distance increment may be flown at the higher cruise altitude, which is always more advantageous in terms of fuel, and usually also in terms of time. This advantage applies both to the initial descent segment from cruise altitude to the initial transition point, and to descents from one level to another in terminal area operations. The VNAV advantage obtained for both of these descent cases has been evaluated and is presented in this section.

The initial descent segment (from cruise altitude) was evaluated by comparing fuel and time requirements of a VNAV-initiated high speed descent procedure to the requirements of candidate standard descent procedures. Present descent procedures range from the most costly, the initiation of descent when descent clearance is received from ATC, to the least costly, where standard airline "rules of thumb" regarding descent initiation point are used. In order to provide the most conservative estimate of VNAV advantage, "rules of thumb" for each of the five airline aircraft studied have been chosen very carefully in order to provide the best descent possible while insuring arrival at the fix at the desired altitude. The rules chosen do not reflect the wind estimation process, which requires either that wind effect estimates be included or that descents be routinely initiated somewhat earlier. The typical "rule of thumb" involves multiplying the altitude to be lost (in thousands) by some standard factor and adding a standard increment (e.g., "three times altitude difference plus ten"). These "standard factors" have been derived for each aircraft by computing a least-square linear fit to the aircraft descent performance. The resulting data shown in Table 3.6, includes, for each objective altitude, the altitude to be lost (ΔH in thousands of feet) and the distance required to lose it (nm). The slope and intercept parameters of the straight-line are shown below the data values. From these fit values the "rule of thumb" values were selected according to the following criteria:

- Multipliers are even numbers
- Added increments are multiples of five miles
- Resulting descent distance must assure arrival at the desired altitude

Table 3.6 Derivation of Descent Rules of Thumb
(ΔH in thousands of feet, ΔD in miles)

	AIRCRAFT									
CRUISE ALTITUDE	DC-9 31,000		B-727 35,000		DC-8 39,000		B-747 39,000		DC-10 39,000	
Objective Altitude	ΔH	ΔD	ΔH	ΔD	ΔH	ΔD	ΔH	ΔD	ΔH	ΔD
0	31	139.5	35	109.0	39	141.5	39	122.5	39	128.0
5000	26	127.0	30	96.5	34	129.0	34	111.5	34	115.5
10000	21	114.4	25	82.7	29	112.8	29	95.6	29	98.9
15000	16	99.6	20	61.8	24	94.1	24	73.5	24	77.8
20000	11	89.2	15	52.1	19	81.7	19	61.0	19	65.1
Slope	2.56		2.97		3.09		3.22		3.27	
Intercept	60.2		6.2		22.2		-0.6		2.2	
Rule of Thumb	3x altitude difference in thousands +55 = miles		3x altitude difference in thousands +10 = miles		3x altitude difference in thousands +30 = miles		3x altitude difference in thousands +10 = miles		3x altitude difference in thousands +15 = miles	

In order to apply the rules of thumb and compare the results with the VNAV-initiated descent procedure for the initial descent segment from cruise altitude, the post-1982 RNAV terminal area designs described in earlier sections were used. For each terminal area, each arrival route was examined to determine the altitude of the first waypoint where a ceiling altitude restriction was in effect. That altitude was then used for the comparison. The results for each route were multiplied by the traffic demand on that route, summed and divided by total traffic to yield a traffic-weighted average VNAV benefit. Results for each of the two terminal route flow configurations were added in proportion to the percent time each configuration is in use in order to yield a single benefit value (fuel and time) for each aircraft at each terminal. These results are presented in Table 3.7.

The effect of using VNAV on terminal area descent segments (from one level to another in terminal area operations) were evaluated using the RNAV terminal area designs. For these descent segments, where usually only a few thousand feet of altitude are lost, it was assumed again that the VNAV-equipped aircraft would descend at the last timely moment, while the non-VNAV aircraft would initiate descent immediately after crossing each waypoint when the altitude bound at the next waypoint is lower than the present bound. This is analogous to the present common practice of beginning descent during terminal maneuvers immediately when cleared for descent. As before, the non-VNAV aircraft cruises at the lower altitude while the VNAV aircraft cruises higher, deriving a benefit. Each arrival route, from the first altitude-restricted waypoint (same as above) into the final approach fix was evaluated to determine VNAV benefit. Many of

Table 3.7 VNAV Descent Procedure Impact

(Fuel - Pounds, Time - Minutes)

		B-747	DC-10	DC-8	B-727	DC-9
MSY:	Fuel: Init. Desc.	47.0	44.5	78.0	44.5	51.0
	Final Desc.	26.0	10.3	12.4	9.6	7.1
	TOTAL	73.0	54.8	90.4	54.1	58.1
	Time: Init. Desc.	.133	.220	.337	.329	.502
	Final Desc.	.042	.034	.035	.041	.044
	TOTAL	.175	.254	.372	.370	.546
DEN:	Fuel: Init. Desc.	60.0	67.2	88.8	27.2	32.8
	Final Desc.	7.3	3.2	3.6	3.8	3.3
	TOTAL	67.3	70.4	92.4	31.0	36.1
	Time: Init. Desc.	.104	.241	.295	.176	.277
	Final Desc.	.013	.011	.013	.029	.023
	TOTAL	.117	.252	.308	.205	.300
PHL:	Fuel: Init. Desc.	18.9	33.9	65.3	41.1	49.8
	Final Desc.	41.1	17.7	21.0	14.4	10.2
	TOTAL	60.0	51.6	86.3	55.5	60.0
	Time: Init. Desc.	.059	.161	.286	.308	.496
	Final Desc.	.065	.057	.057	.060	.061
	TOTAL	.124	.218	.343	.368	.557
MIA:	Fuel: Init. Desc.	26.0	42.0	68.0	32.0	38.0
	Final Desc.	37.7	15.7	17.3	13.8	10.1
	TOTAL	63.7	57.7	85.3	45.8	48.1
	Time: Init. Desc.	.085	.203	.304	.252	.394
	Final Desc.	.064	.053	.054	.062	.065
	TOTAL	.149	.256	.358	.314	.459
SFO:	Fuel: Init. Desc.	23.5	39.5	67.0	34.2	41.5
	Final Desc.	27.3	7.4	9.2	9.0	7.2
	TOTAL	50.8	46.9	76.2	43.2	48.7
	Time: Init. Desc.	.079	.192	.299	.265	.418
	Final Desc.	.044	.024	.026	.040	.046
	TOTAL	.123	.216	.325	.305	.464
ORD:	Fuel: Init. Desc.	26.5	42.5	68.5	32.0	37.5
	Final Desc.	45.1	16.6	19.2	14.7	10.7
	TOTAL	71.6	59.1	87.7	46.7	48.2
	Time: Init. Desc.	.086	.205	.305	.249	.388
	Final Desc	.074	.055	.056	.063	.067
	TOTAL	.160	.260	.361	.312	.455
JFK:	Fuel: Init. Desc.	83.0	73.0	98.5	43.5	46.5
	Time: Init. Desc.	.163	.262	.332	.266	.401
LGA:	Fuel: Init. Desc.	29.0	45.5	69.5	27.0	33.5
	Time: Init. Desc.	.099	.225	.313	.219	.334
EWR:	Fuel: Init. Desc.	40.5	54.0	74.5	25.5	28.5
	Time: Init. Desc.	.106	.238	.308	.189	.288

these routes have several descent segments. The benefit for each route was combined with other routes, as before, to yield a traffic weighted average for each terminal studied. Recent modifications to the New York terminal area designs prevented inclusion of final descent data for those three airports in Table 3.7. Their absence has no impact on the regression analysis for extrapolation purposes, described below, since New York and Chicago were not intended to be included. The results of the studies of VNAV benefits in each of the two cases described above are presented in Table 3.7, where fuel values are in pounds and time in minutes. Most of the fuel values are on the order of fifty to sixty pounds and most time values center around 0.3 minutes. As discussed before, these values are quite conservative since the rule of thumb initial descent procedures represent a very optimistic conventional descent; many airline operators do not adhere to such stringent and precise descent procedures.

An attempt was made to determine a regression equation which could be used to relate VNAV benefit to operation rates at each airport. The same methods as were used in Section 3.1.2 were applied, i.e., only five lower density airports were used, and the regression parameter used was 1974 itinerant operations minus GA itinerant operations. The resulting regression equations were almost totally insensitive to the operations count parameter. Therefore, it was not deemed to be advisable to apply the regression equations in the manner done in Section 3.1.2. Rather the traffic weighted combination for those five airports was formed, based upon the projected 1984 annual operations for each aircraft at each of the five airports. These values were then multiplied by the number of operations for each aircraft type projected in 1984 over the sixty major and medium density terminals. These results in terms of fuel and time, are presented in Table 3.8.

Table 3.8 Aggregate Annual VNAV Descent Benefit (Fuel-Pounds, Time-Minutes)

	B-747		DC-10		DC-8		B-727		DC-9	
	Fuel	Time	Fuel	Time	Fuel	Time	Fuel	Time	Fuel	Time
Traffic Weighted Average	56.7	.132	55.8	.239	81.3	.340	44.7	.305	49.9	.459
Sixty Airport Ops (1984)	406,000		1,253,000		419,000		3,770,000		3,634,000	
Total Aircraft Benefit	23.0m	54K	69.9m	300k	34.1m	142k	168.5m	1150k	181.3m	1668k
Aggregate Benefit: Fuel 476.8 Million Pounds, Time 3314 Thousand Minutes										

3.1.3 Effects of Alternate Descent Procedures on Benefits

The 2D RNAV benefits and VNAV benefits computations for arrival aircraft were performed based upon the assumption that standard high speed descent procedures are used. Since airlines do not necessarily adhere to the high speed descent schedule, but conduct alternate types of descents, it is of interest to determine what, if any, effect the selection of alternate procedures would have on RNAV and VNAV benefits. The other standard descent procedure used in published handbook data is the long range (fuel economic) descent, which is considerably different and represents the probable opposite extreme which would ordinarily be used. Since performance data was available for this procedure (for four aircraft types only), it was selected as the other candidate for comparative purposes. To illustrate the different speed schedules used for the two procedures, the DC-8 procedures are as follows:

HIGH SPEED DESCENT		LONG RANGE DESCENT	
Descent Speed	Altitude	Descent Speed	Altitude
Mach 0.83	to 26,600 ft	Mach 0.78	to 37,450 ft
340 KIAS	to 10,000 ft	250 KIAS	below 37,450 ft
250 KIAS	below 10,000 ft		

The differences in the procedures in terms of performance are that the high speed procedure requires less time but more fuel than the long range procedure. For example, for a DC-8 descent from FL390 to sea level, the long range descent saves 452 lbs of fuel, but extends descent time by 3.7 minutes.

The RNAV terminal area analysis presented in Section 3.1.1 for arrivals was repeated using the long range descent data for those aircraft for which such data was available (DC-9, B-727, DC-8 and DC-10). The purpose of this analysis was to determine if the RNAV savings over VOR are comparable for this descent procedure to the savings of RNAV over VOR for the high speed descent procedure. Since these two procedures represent the extreme in different descent procedures, the results would then be valid for other procedures. The results of this study are presented for each city and each aircraft along side of the original RNAV benefits computed using the high speed descent procedure in Table 3.9. In that table the data shown are the combined data for both flow directions. An examination of the resulting data shows that the differences are very minor and do not show any consistent trend. Therefore it may safely be assumed that the choice of either of these descent procedures, or others in between, would have no significant effect upon the benefits to be derived from RNAV terminal procedures over VOR procedures as presented in Section 3.1.1.

In Section 3.1.2 the benefits available to VNAV equipped users resulting from the use of VNAV guidance to initiate descent have been presented. In that analysis, the difference between the use of VNAV guidance as opposed to "rule of thumb" operational techniques has been computed. By allowing the initiation of descent at the last possible moment, VNAV prevents unnecessary cruise at a low altitude, which occurs when descent is initiated early as in a conventional descent procedure. If descent procedures other than the high speed descent, such as the long range descent, were to be substituted, VNAV would still provide the same advantage, i.e., it would allow more accurate control over the descent initiation point than is available through conventional means. Therefore, the VNAV benefit computed in Section 3.1.2 would be realized regardless of the particular descent procedure employed. Results of a real time terminal area simulation conducted at NAFEC [11] indicated that pilot selection of VNAV descents had no impact on the controllers handling of traffic or the ability of the aircraft to realize 2D benefits.

Table 3.9 2D RNAV Arrival Benefit - Comparison of Benefits of RNAV Over VOR Achieved with High Speed and Long Range Descent Procedures

	DC-9				B-727				DC-8				DC-10			
	High Speed		Long Range		High Speed		Long Range		High Speed		Long Range		High Speed		Long Range	
Airport	Fuel (lb)	Time (min	Fuel (lb)	Time (min)	Fuel (lb)	Time (min)	Fuel (lb)	Time (min)	Fuel (lb)	Time (min)	Fuel (lb)	Time (min)	Fuel (lb)	Time (min)	Fuel (lb)	Time (min)
PHL	38.5	.417	36.8	.389	53.8	.434	64.9	.420	91.3	.426	92.1	.413	91.8	.443	94.5	.425
DEN	-3.0	-.089	1.2	.010	2.8	-.090	3.6	.012	-17.6	-.092	3.6	.002	-19.9	-.091	0.6	.002
MSY	32.9	.377	34.5	.425	50.7	.393	50.7	.346	74.5	.429	73.8	.436	94.8	.418	93.5	.438
ORD	51.8	.578	51.5	.572	76.3	.599	86.1	.602	124.8	.628	125.3	.620	137.9	.639	140.2	.636
MIA	89.9	.992	86.5	.942	124.8	1.015	147.3	.978	202.9	.968	204.7	.949	208.1	.995	212.2	.958
SFO	123.9	1.420	125.0	1.438	178.7	1.403	191.9	1.400	263.3	1.388	264.0	1.390	301.7	1.378	378.0	1.385
JFK	344.1	3.662	335.6	3.690	482.1	3.664	540.8	3.757	762.6	3.681	751.0	3.705	826.3	3.733	824.6	3.734
LGA	408.4	4.310	395.9	4.131	579.4	4.455	678.1	4.395	953.9	4.452	961.0	4.378	980.5	4.592	1006.6	4.479
EWR	134.3	1.346	131.2	1.249	193.6	1.421	226.4	1.361	323.8	1.443	323.7	1.379	326.2	1.491	330.0	1.413

3.2 HIGH ALTITUDE ROUTE LENGTH ANALYSIS

Studies aimed at quantifying RNAV enroute distance savings have been performed using a NAFEC designed charted RNAV structure compared with the existing VOR structure [4]. In these studies traffic was distributed over VOR routes between each airport pair according to historical data and was distributed over alternate RNAV routes between each airport pair according to criteria developed as part of the study. Since the traffic distribution over the VOR structure reflected actual, real world traffic situations, it included some percentage selection of VOR routes for purposes of minimizing wind mile distance. The distribution of traffic over RNAV routes, however, was based only on accommodating the traffic while minimizing ground mile distances, and also did not include the effect of restricted areas on the RNAV route structure. The RNAV benefits measured were based on the traffic weighted average difference in ground miles between the distributed VOR traffic and the distributed RNAV traffic between each airport pair in the structure. This method of analysis left unanswered two basic questions:

(1) What is the traffic weighted average wind mile difference between the distributed VOR and RNAV traffic in the structures analyzed?

(2) What would the traffic weighted average wind mile difference be between distributed VOR and RNAV traffic if the RNAV route design and traffic distribution had also been based on consideration of real world selection of weather routes and/or an RNAV structure which was constrained by restricted areas?

The current study was conducted to provide a calibration of the NAFEC study in order to determine what biases, if any, the consideration of weather route selection and restricted areas would have on the percent enroute distance savings expected from RNAV, as determined in the NAFEC study.

3.2.1 Alternate Weather Route Analysis

3.2.1.1 Study Approach

There are a variety of software capabilities which are currently being used to generate flight planning information, in a weather environment, whose results could be applicable to this study. Many of the major air carriers, as well as several independent service organizations have "flight planning" programs, one of the basic objectives of which is to compare the various alternate routes and establish that which is most favorable. Because of the existance of this flight planning capability, the option of developing the desired software was rejected pending verification that a suitable subcontractor could be found. Communications were initiated with several of the organizations with the appropriate capabilities for this study. These efforts resulted in isolating two organizations that were both willing and capable of providing the required support:

United Air Lines (UAL), and
Lockheed (JETPLAN Service).

The capabilities of these organizations, designed to satisfy different requirements, also varied. The UAL program evaluates and selects a "best route" from a pre-defined set of routes; but in so doing, provides the results (wind miles) of each route comprising the given set. The JETPLAN program is more flexible in that a pseudo optimum route is developed for the prevailing conditions each time the program is run. This results in considerably more alternate routes being evaluated, nominally, but only the data relevant to the selected route is made available to the user. It was established that the JETPLAN service would provide a better means of analyzing a pre-planned direct environment, but that the UAL program was better suited to addressing a charted route environment, which was of primary interest in this study. The UAL program was therefore selected.

The definition of route structures to be simulated involved selection of appropriate airport pairs, and the specification of VOR and RNAV weather routes for each airport pair.

The selection of the airport pairs was constrained to some extent by UAL's desire that the results of this study be compatible with independent UAL evaluations of RNAV operations. A set of six airport pairs whose mix of distance, orientation and location was compatible with the study objectives was mutually agreed upon for the subsequent flight planning analysis. These airport pairs are listed below:

(1) Chicago-O'Hare (ORD) to/from Denver (DEN)
(2) Chicago-O'Hare (ORD) to/from Los Angeles (LAX)
(3) New York-Newark (EWR) to/from Chicago-O'Hare (ORD)
(4) Washington, D.C.-Dulles (IAD) to/from Los Angeles (LAX)
(5) Miami (MIA) to/from Cleveland (CLE)
(6) New York-Kennedy (JFK) to/from Seattle (SEA)

Having selected this set of airport pairs to be examined in this study the next task was to define the corresponding route structures. The VOR alternate routes currently stored and flown by UAL seemed to satisfy the VOR route structure requirements. Since UAL developed and utilized a sophisticated flight planning capability over a period of years, it is not unreasonable to expect that their choice of VOR routes retained for evaluation by their flight planning program would approximate an optimum set of VOR routes. However, since a complete RNAV alternate route structure does not currently exist, the best method to define a reasonable and representative RNAV structure for use in this study was not obvious. The definition and justification of a single representative RNAV structure would have been difficult, if not impossible to accomplish. As a result several RNAV route structures were included in the analysis.

In all, two VOR (differing only in the terminal area) and four RNAV route structures were created for each airport pair. An additional VOR and two additional RNAV structures were created as combinations of the basic sets subsequent to the processing of the results. While the redundancy of structures was considered necessary to minimize the possibility of unrepresentative results, the various structures were also developed based upon different constraints and objectives in an effort to extract the maximum information from the study. The characteristics of each structure and the manner in which they were developed are presented in the next section.

3.2.1.2 Data Base Development

The data base associated with the alternate weather route analysis included that information required to describe each route of each postulated route structure and the data necessary to characterize the weather of those days selected to be used for flight planning simulations. To place the weather requirements in the proper perspective it is helpful to summarize the UAL flight planning program. This program can best be described as a two phase process. The first phase is used to select the desired route from the set of candidate routes of a given structure stored by UAL for the designated airport pair. The second phase defines the optimum vertical flight profile for the route selected in Phase 1, considering type of aircraft, gross weight at takeoff, criteria for optimization such as minimum fuel or minimum flight time and other factors. While this final flight profile was of interest, it was the results of the first phase which were directly utilized in this study. The output format of both Phase 1 and Phase 2 are illustrated in Appendix B of this report.

Weather Sample

The effect of winds are simulated for the Phase 1 process by defining a wind vector for each route segment. The characteristics of these vectors are determined by processing weather data obtained from the National Weather Service at 12 hour intervals, updated when appropriate, based upon communications from UAL weather reporting flights. This information is processed, producing a weather data base 500, 400, 300, 250 and 200 millibars (approximating 18, 24, 30, 35 and 39K foot altitudes, respectively) on a grid of roughly 2-1/2° latitude by 5° longitude. For the Phase 1 (route selection) process this information is converted in an average wind by weighting the winds at 300, 250 and 200 millibars 22, 50 and 28 percent, respectively. Linear interpolation between the grid points (2-1/2° lat-5° long) is utilized to obtain the desired wind information at the beginning and end of each route segment. The average of these values is then applied to the entire segment. This process is repeated for winds during each cruise segment of the route. The climb portion of each flight is simulated as identifying the wind vector at this fix which is closest to a point 175 nm from the departure airport, but is not greater than 175 nm from the airport. The magnitude of this vector is halved and it is applied during the first 30 minutes of flight. The aircraft heading during climb is approximated by setting it equal to the heading between the airport and the first fix. The descent leg of each flight is simulated in a similar manner except that the distance is changed from 175 nm to 140 nm and the duration of the descent is set at 15 minutes. A more sophisticated and accurate technique is used in the Phase 2 program which generates the actual flight plan used by UAL in their operations.

Route Structure Design

The route structure data base requirements are summarized below:

(1) Definition of the terminal waypoints (both RNAV and VOR).
(2) Normalization of the VOR terminal points and terminal segment lengths.
(3) RNAV route structure development.
(4) Route structure implementation at UAL.
(5) Validation of the data base.

The purpose of the first two tasks was to assure that the ground rules and assumptions underlying the RNAV and VOR structures were compatible. The RNAV route structure development involved both the satisfying of specific objectives associated with each of the structures, as well as specifying the routes.

To insure compatibility between studies addressing RNAV benefits which occur in the terminal areas and those of this study dealing with enroute benefits, efforts were made to utilize a common interface. In this case, this interface was the terminal area waypoints. Information was obtained identifying terminal waypoint locations which reflected the prevailing wagon wheel terminal area design philosophy for each of the nine airports examined in this study. An example of the resulting arrival and departure locations is illustrated in Figure 3.1. The location of the VOR arrival and departure fixes associated with the minimum ground mile VOR route is also shown. The location of these points was approximated by the intersection of the terminal area circle (at a radius of either 45 or 60 nm, depending upon the specific terminal area) and the estimated flight path between the airport and UAL's first VOR enroute fix outside of the terminal area circle.

Since the UAL flight planning program considers the entire flight, including both terminal area and enroute components, it was necessary to adjust the terminal area route structure to null out any bias which could influence the route selection process which, for purposes of the analysis, were considered to be an exclusive enroute effect. This was accomplished by simulating the airport location at the center of the terminal area and providing a great circle route segment from each terminal area fix to the airport. These simulated conditions resulted in all routes having common terminal area route lengths, either 45 or 60 miles depending on the terminal area.

One exception was made to this approach in order to reflect the impact of the wide variation in VOR terminal route lengths that are prevalent at some airports. This was accomplished by incorporating a terminal area route distance into the UAL route structure data base which, when added to the great circle distance between the terminal area waypoint and UAL's first enroute fix, would equal the actual distance identified by UAL between the airport of the first fix of each VOR route. This procedure is illustrated in Figure 3.2. Thus two VOR route structures different only in terminal area route lengths, were defined for each airport pair: The VOR A structure with terminal area routes lengths set equal to those of corresponding RNAV routes (45 or 60 nm) and the VOR B structure which approximated the actual distance between the airport and UAL's first fix, as currently flown. To account for the VOR terminal route distance variations without jeopardizing the validity of the VOR-RNAV enroute comparisons required the use of both structures. The VOR B structure was used to select a VOR route on any given day based on minimum wind miles, while the VOR A structure was used to define the RNAV compatible wind miles for that route corresponding to the VOR B selected route. In most cases the same route produced the minimum wind miles in both the VOR A and VOR B structures. However, the results of this process was to produce average VOR wind miles slightly larger than the values which would have been derived using only the VOR A minimum wind mile routes. A VOR C route structure name was established to identify the results of the

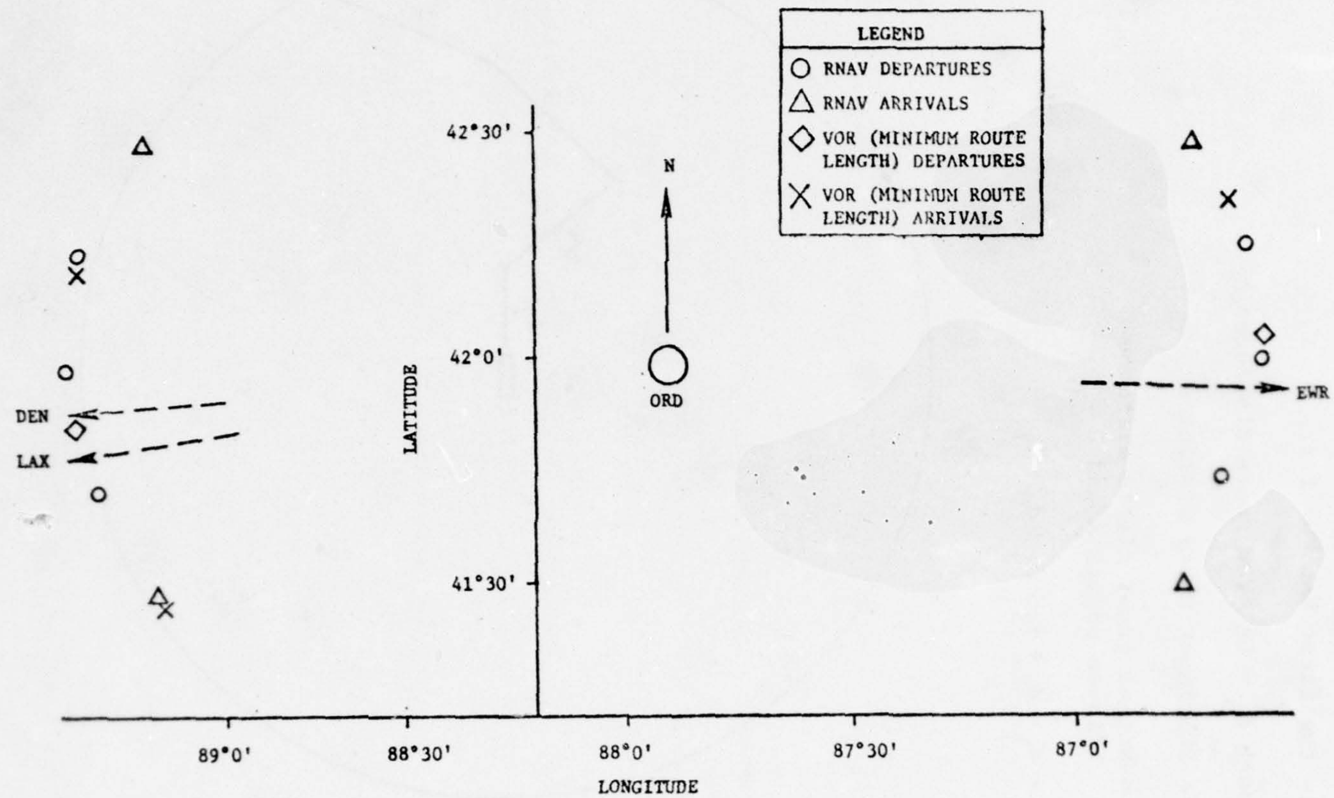

Figure 3.1 Alternate Weather Route Study, Chicago Terminal Area Arrival and Departure Points

Point A is the intersection of UAL VOR route and 45 or 60 mile circle.

Point B is the first UAL VOR fix.

d_1 through d_5 = UAL VOR route distances

d_6 & d_7 = SCI input route distances

d_7 = actual great circle distance between points A and B

$$d_6 = d_1 + d_2 + d_3 + d_4 + d_5 - d_7$$

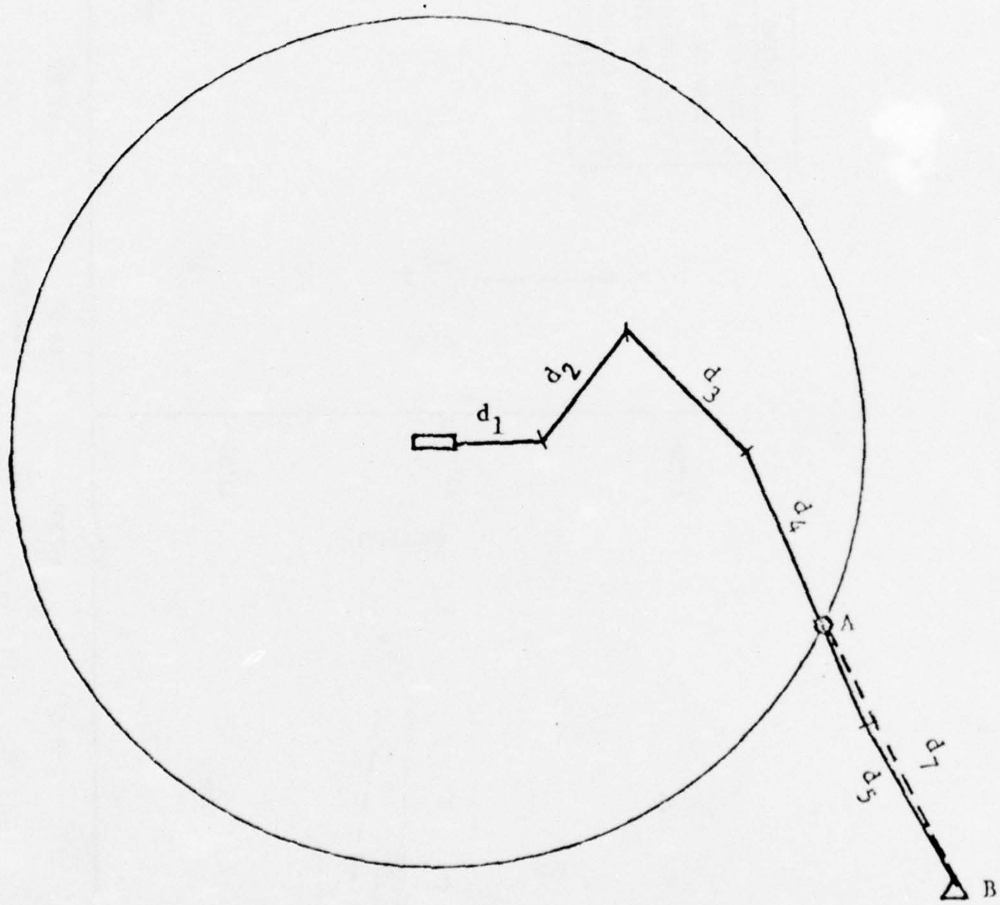

Figure 3.2 Determination of First or Final Fix Distance to Airfield VOR B Structure

aforementioned process of using both VOR A and VOR B data to establish a realistic, yet RNAV route compatible, set of VOR wind mile characteristics.

RNAV Route Structures

Four distinct RNAV route structures resulting primarily from different design philosophies were developed for this study.

The first structure is what will be referred to as the UAL/RNAV route structure. This route structure was developed by United Air lines, but subject to the constraints imposed by the terminal waypoints previously defined. The structure was intended to reflect a practical, achievable, yet near optimum RNAV structure. An "optimum" RNAV alternate routes structure would generally be defined as one which included the "optimum" route on any given day. As such, a virtually infinite number of routes would be required. As will later be shown, for given airport pairs, a greater number of routes will reduce the average route length (as measured in wind miles). A point of diminishing returns exists, however, as the incremental benefit of additional routes is outweighted by the data management costs. The UAL/RNAV route structure reflects the UAL's subjective solution to this trade-off problem with regard to both the number of routes and their general design.

Inherent within their designs are two primary assumptions. First, they adhere to the principle that, in the long run, the great circle arc (connecting the appropriate terminal waypoints) is the average candidate "preferred" route. The UAL/RNAV structure for each airport pair therefore includes a route of this form. The second assumption pertains to the geometric shape of the other (alternate) routes. Specifically, the preferred shape was assumed to be a smooth curve (with its maximum displacement from the great circle arc occurring at the mid-point) connecting the terminal waypoints. With the various alternate routes being distinguished by their deviation from the great circle arc. The UAL structures are described best as a "family of concentric football-shaped routes". The maximum displacement (from the great circle arc) of the outermost routes, the number of routes and consequently their separation were determined from specific characteristics of the airport pairs. This determination was based upon UAL's considerable practical experience. The UAL/RNAV route structure for the airport pair LAX-ORD is presented in Figure 3.3.

The UAL structure was developed from its conception to provide a set of alternate routes and did so without regard to the preferred and/or alternate routes of any neighboring airport pairs. This design philosophy differs from that utilized in FAA/RNAV route design studies. Specifically the FAA approach emphasizes the efficient design of "preferred" RNAV routes. The best example is the RNAV route structure created by NAFEC. This structure illustrated in Figure 3.4, includes some 429 airport pairs (2-way) and is expected to be adequate to accommode 92% of high altitude traffic with minor extensions to include airports in close proximity to routes in the structure. It was designed, however, based upon preferred (great circle arc) routes only and with extensive consideration given to overall traffic manageability. Of particular interest in this study, was whether or not a structure designed according to these guidelines could provide an adequate set of alternate weather routes as a part of the basic route structure. To address this question, the SCI/NAFEC and FAA/NAFEC structures were constructed by utilizing the routes

UAL Flight Number 55

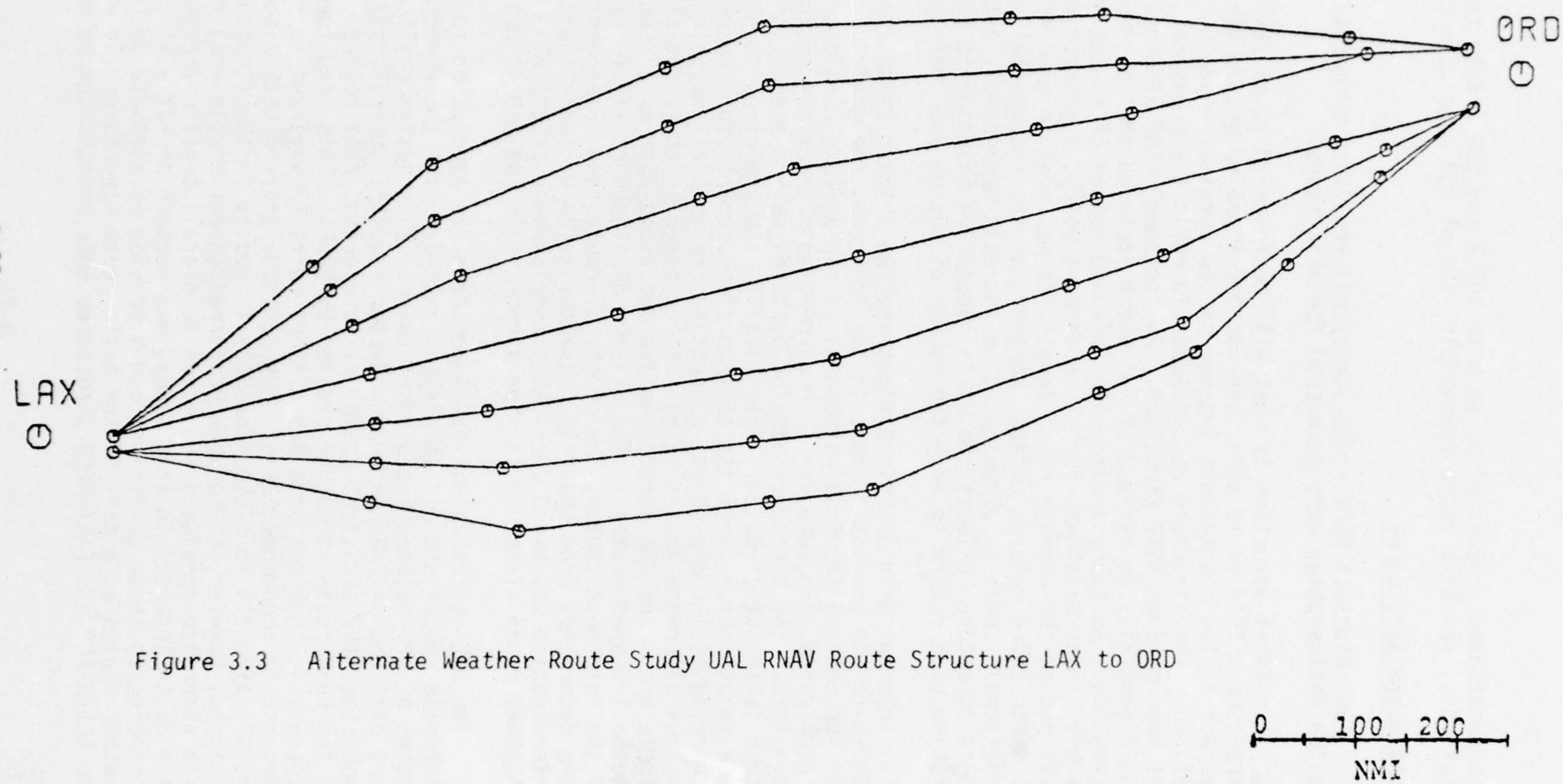

Figure 3.3 Alternate Weather Route Study UAL RNAV Route Structure LAX to ORD

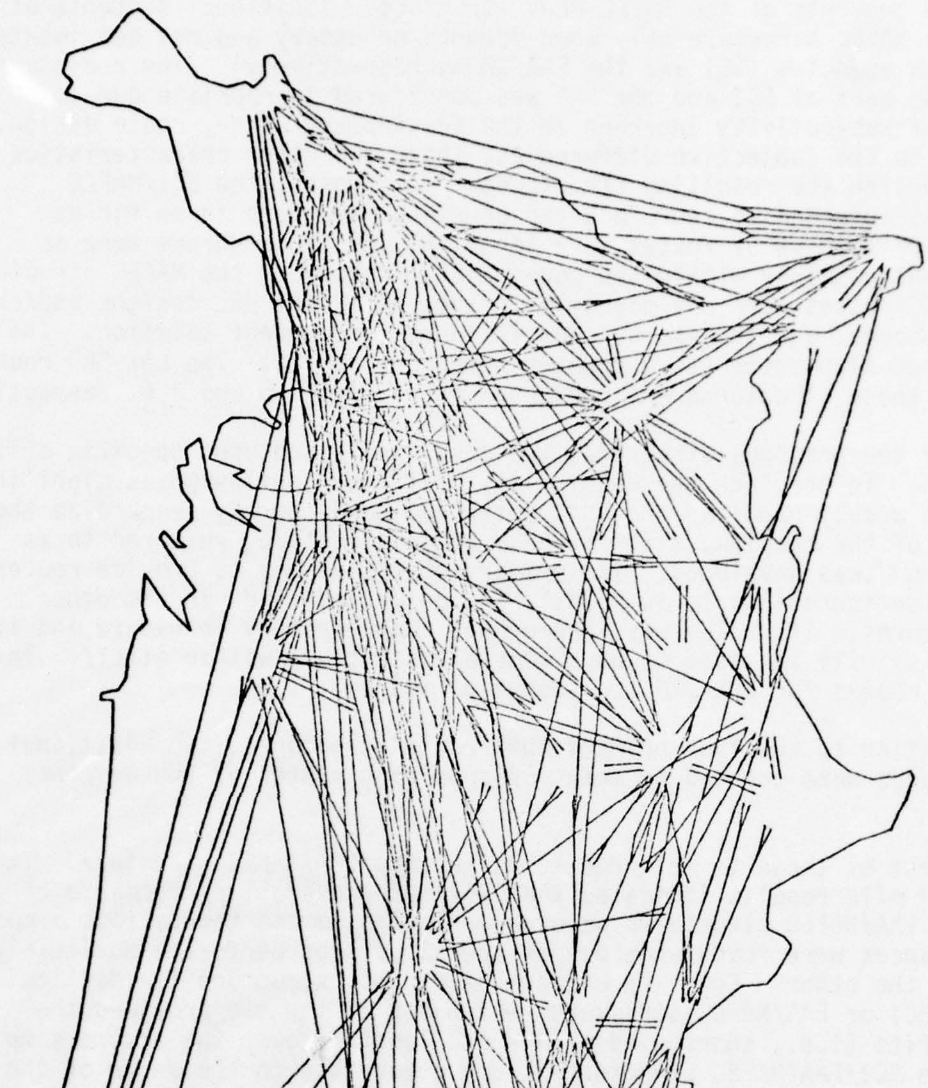

Figure 3.4 "429" Airport Pair NAFEC RNAV Route Structure

and/or route segments of the NAFEC RNAV structure. Additional segments were added to the NAFEC structure only when "deemed necessary and not detrimental" by the design agencies (SCI and the FAA/SRDS, respectively). The redundant effort on the part of SCI and the FAA was considered appropriate due to the high level of subjectivity inherent in the development of any route design. In addition to the subjective differences, there are other characteristics which distinguish the resulting structures. In general, the SCI/NAFEC structure was intended to reproduce the UAL/RNAV structure in so far as possible. The numbers of routes were identical and their shapes were as similar as was possible within the constraints imposed by the NAFEC structure. The FAA/NAFEC routes were not directly influenced by the UAL designs and/or design philosophy, and therefore, constitute an independent solution. The FAA structures also encompass a greater number of routes. The LAX-ORD routes for each of these structures are presented in Figures 3.5 and 3.6, respectively.

Each of the previous structures was developed based upon specific design philosophies. To preclude the possibility that these philosophies might in some respect unduly handicap the RNAV potential, and thereby jeopardize the credibility of the results, a fourth RNAV route structure, referred to as the FAA "Direct", was developed. Its primary objective was to provide routes of various configurations so as to fill any potential voids in the other route structures. Its value was, therefore, complementary in nature and it was not necessarily intended to be a complete structure within itself. The FAA "Direct" routes for LAX-ORD are shown in Figure 3.7.

In addition to the four primary RNAV route structures, two additional RNAV structures were created by means of combining routes of the original structures.

The first of these is referred to as the SCI/FAA/NAFEC structure. The initial wind mile results indicated that while the overall performance of the SCI and FAA/NAFEC structures were very similar, among the various airport pairs, instances were found when one of the structures performed noticeably better than the other. For each airport pair, this structure is identical to either the SCI or FAA/NAFEC structure, whichever of the two provided the larger benefits (i.e., short wind mile route lengths) over the entire sample period. The SCI/FAA/NAFEC structure is not comparable to the union of the two individual structures because the selection of which structure was better, was not done on a day-by-day basis.

The second additional structure is referred to as the "pre-planned" structure. In constrast to the combining procedure used for the SCI/FAA/NAFEC structure, the "pre-planned" structure is the union of all routes of all structures (VOR A included). The wind mile results for a given airport pair and sample day were obtained by utilizing whichever route of any set that produced the minimum wind miles. The "pre-planned" structure was intended to approximate the environment which its name implies to the maximum extent that was possible within this study. It is important to note that the "pre-planned" results, from this view point, would be conservative because the selection process was limited to a finite number of routes, none of which was designed to provide an optimum route for a given weather pattern.

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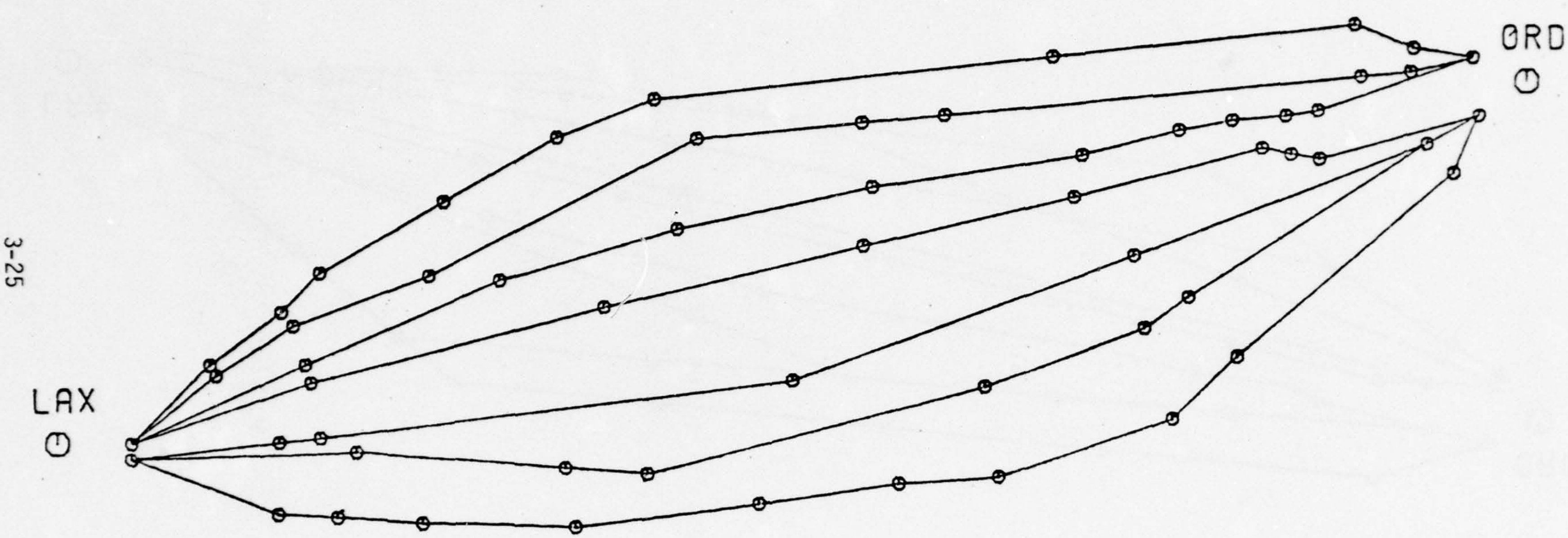
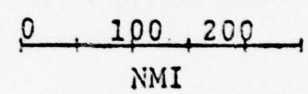


Figure 3.5 Alternate Weather Route Study SCI/NAFEC RNAV Route Structure LAX to ORD



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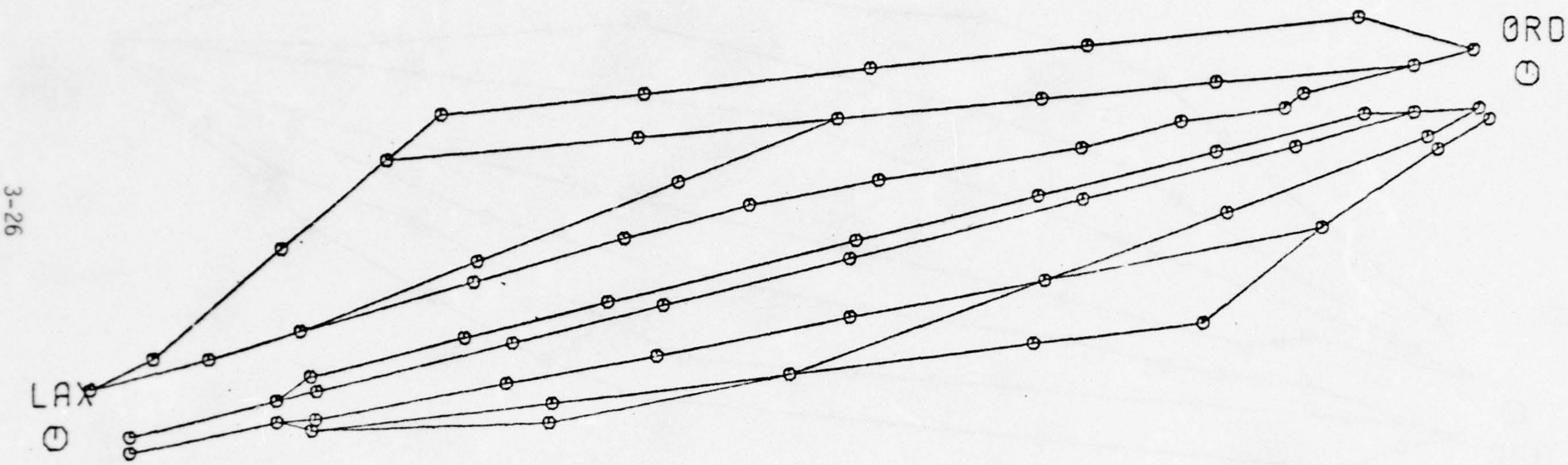

Figure 3.6 Alternate Weather Route Study FAA/NAFEC RNAV Route Structure LAX to ORD

0 100 200
NMI

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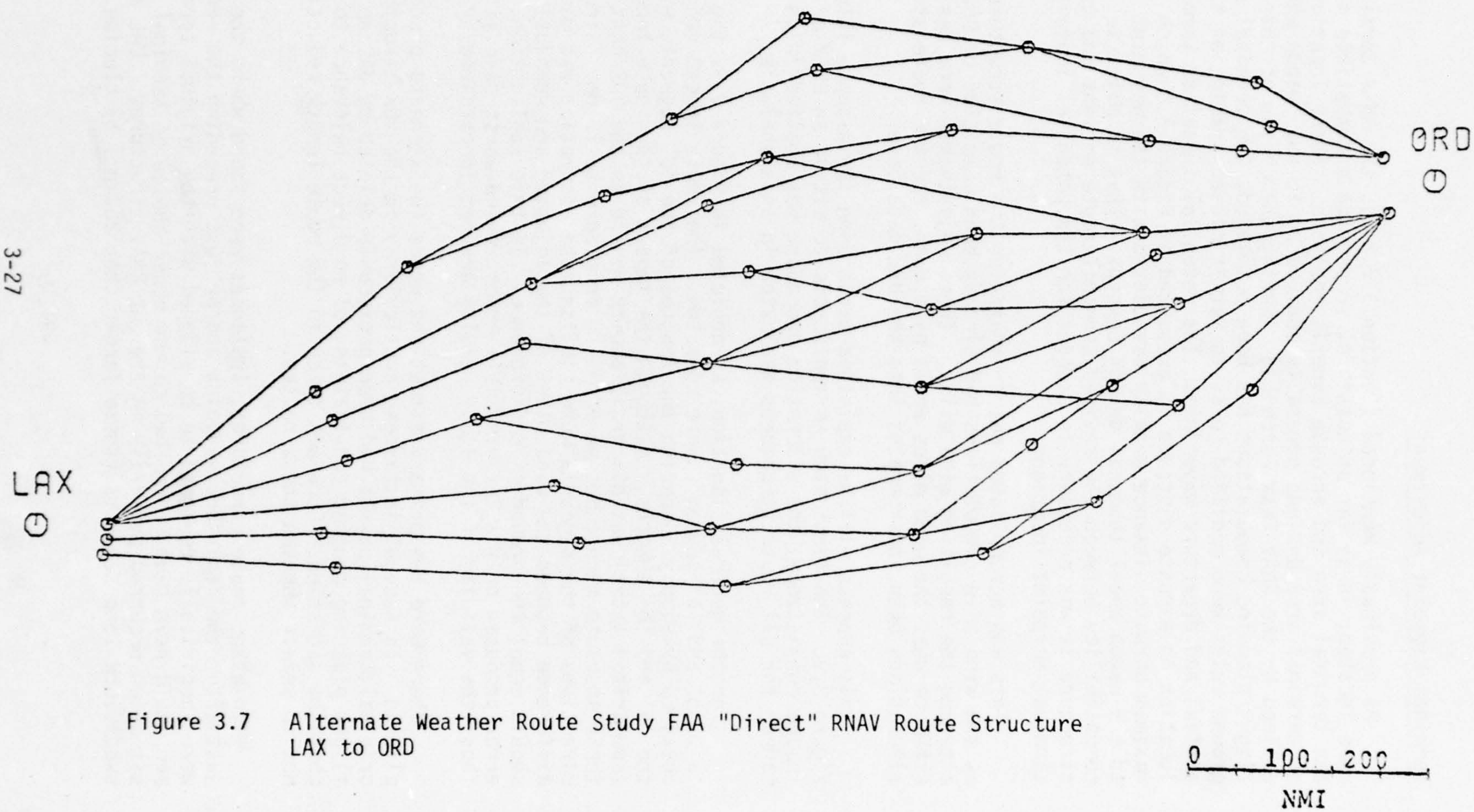


Figure 3.7 Alternate Weather Route Study FAA "Direct" RNAV Route Structure LAX to ORD

Terminal Waypoint Adjustment

As previously mentioned (Section 3.2.2.1), the RNAV terminal waypoints were located, in so far as possible, to provide a compatible interface between the terminal area and enroute benefit analyses. These locations were predicated on terminal area designs generally conforming to the "wagon wheel concept" as defined by the RNAV Task Force [1]. During the course of this study after UAL's flight planning computations has been completed, the terminal area design ground rules were modified so as to permit closer spacing of the terminal arrival and departure waypoints. The potential impact of terminal waypoint location on enroute distance is presented in Figure 3.8 which illustrates the maximum enroute distance penalty associated with the waypoint location conforming to the wagon wheel terminal design concept. Thus to maintain the desired compatibility between the revised terminal route designs and the enroute structure it was necessary to account for the potential improvement in the terminal waypoint locations.

This was accomplished not by modifying the route structures themselves, as the wind mile computations had already been completed by UAL, but by altering the resulting wind miles. These adjustments were designed to estimate what the wind miles would have been, had the route structure alterations been incorporated into the UAL data base.

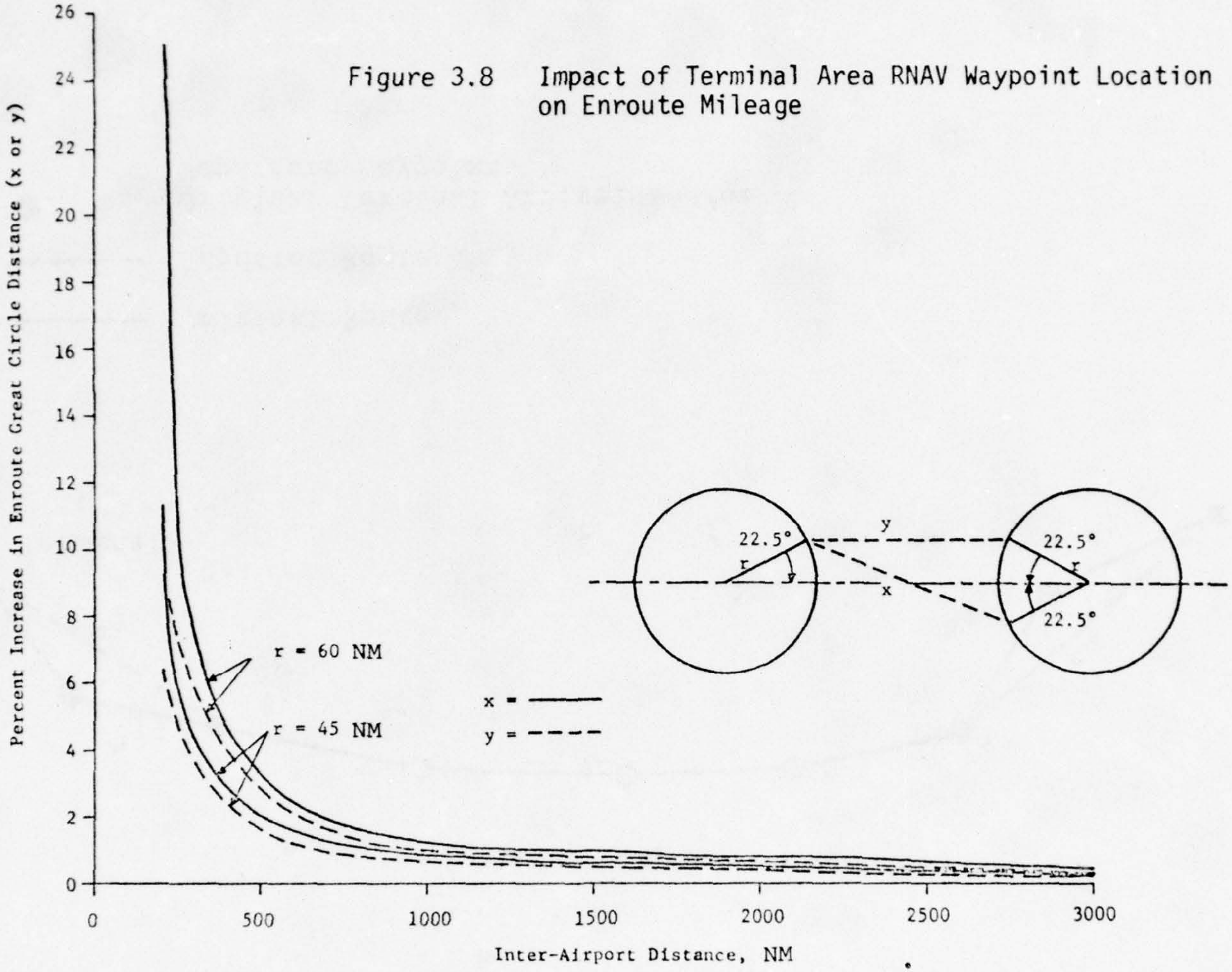
This process will be explained based upon the example illustrated in Figure 3.9. The first step is applicable to either an RNAV or VOR route. To insure consistency, the alteration procedure was applied in an identical manner for all route structures evaluated in this analysis.

For the general situation, as depicted in Figure 3.9, the lengths of the 'a', 'b' and 'c' segments were computed. The route length reductions were obtained by simply comparing the lengths of the 'c' segments with the sum of the 'a' and 'b' lengths. Although the impact of the route length reductions (summarized later) was discernible with regard to the VOR/RNAV comparison, their absolute magnitudes were small, from zero to 15 nm. Since the general directions of the segments were similar, the assumption was made that the difference between the wind miles of the adjusted and unadjusted routes should equal the ground mile difference. In this application, a ten percent error produced only a 2nm wind mile error in the worst case situation. Thus, the validity of the study results are not jeopardized by this procedure.

There were two primary situations where the standard procedure alone was altered. In several instances, particularly in the VOR structures, the original terminal points had been previously deleted by UAL so that certain flight planning program constraints, of no direct relevance to this study, could be satisfied. Care was taken in the route length reduction process not to unduly shorten these routes.

In other route structures, instances were found where the waypoint just after the departure waypoint and/or just preceding the arrival waypoint were specifically designed to be aligned with the original terminal waypoints and would have been ill-suited to any other choice of terminal points. This situation occurred primarily in the UAL RNAV structures. UAL automatically subdivided long segments (those larger than 250 nm) by placing waypoints

Figure 3.8 Impact of Terminal Area RNAV Waypoint Location on Enroute Mileage



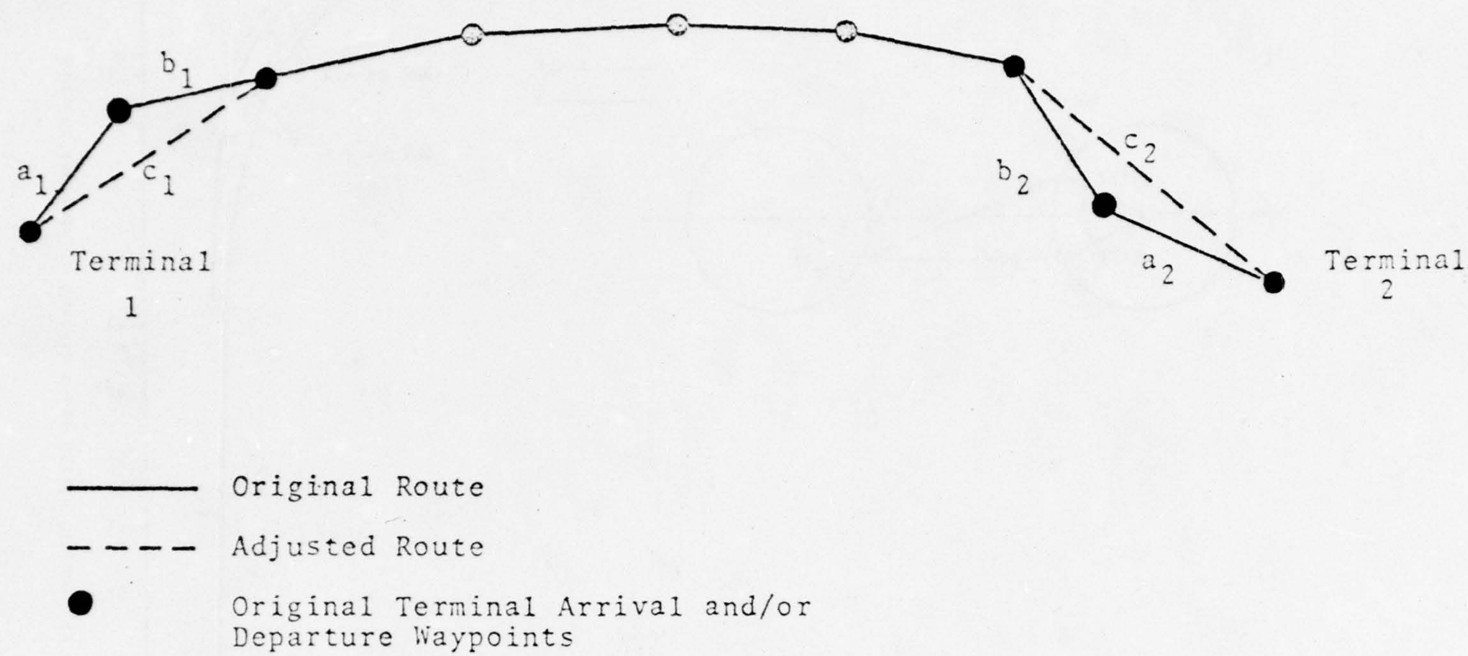


Figure 3.9 Terminal Waypoint/Route Length Adjustment Example

every 250 nm. For example, the automated process would place a waypoint 250 nm along a 251 nm segment. This resulted in distinct waypoints in very close proximity to one another, specifically, in this example, 1 nm. In instances of this type, the terminal point and the adjacent point were both eliminated in the adjustment process. However, the general characteristics of the routes were never altered.

3.2.1.3 Alternate Weather Route Study Results

A total of 39 daily weather samples (based upon their diverse characteristics) were selected by UAL from between March 23 and May 14, 1975 for use in this study. A total of six route structures (UAL/RNAV, SCI/NAFEC, FAA/DIRECT, FAA/NAFEC, VOR A and VOR B) were defined for each of the 12 unidirectional airport pairs selected for evaluation in this study. Thus for each weather sample UAL produced a total of 72 flight plans for the selected routes of each structure plus identifying the ground miles for every route in the set.

Before presenting summaries of ground mile and wind mile results from the UAL data, it is appropriate to again define briefly the VOR and RNAV route structures which were utilized to aid the reader in the interpretation of those results. Table 3.10 presents a summary of these route structure definitions.

In the analysis of the results of this study, two factors are of primary concern: (1) the total RNAV benefit, expressed in terms of percentage wind mile savings on the selected individual RNAV weather routes compared with corresponding selected individual VOR routes; and (2) the relationship of the RNAV weather route benefit measured in this study of twelve airport pairs, on an individual route basis, to the ground mile RNAV benefit measured in the previous NAFEC study which compared traffic distributed over several VOR and several RNAV routes between the same airport pairs in a 429 airport pair structure. The first factor is indicative of the benefit available through RNAV when capacity and traffic flow considerations do not preclude the selection of either the shortest RNAV route or the shortest VOR route. The second factor provides a calibration of the no wind analysis which was based on real world constraints of required traffic distribution, and will allow an interpretation of those benefits which includes consideration of requested weather routes in the distribution of that traffic. In other words, the first factor is indicative of best case VOR route assignment (and worst case RNAV benefit), and the second factor is representative of distributed route assignment and corresponding traffic weighted average RNAV benefit.

The basic data output from the UAL simulation which was used in the analysis of these two factors are summarized in Tables 3.11, 3.12 and 3.13. Table 3.11 presents the terminal center to terminal center ground miles of the best ground mile routes for each route structure and each airport pair. The figures in parentheses are the percent of average ground miles over great circle distances. The "pre-planned" column is the best of the other 6 structures over the period, and should be compared with the VOR C column, as indicated in Table 3.10. The ground mile distance in Table 3.11 may differ from corresponding route lengths in the NAFEC analysis [4] since they are measured prior to terminal waypoint adjustment (see Section 3.2.1.2),

TABLE 3.10

WEATHER ROUTE ANALYSIS ROUTE STRUCTURE DEFINITION

Route Structure	Definition
Vor A - used to define terminal distance for RNAV comparison	UAL VOR weather routes with terminal lengths set equal to those of corresponding RNAV routes
VOR B - used to select minimum wind mile route	UAL VOR weather routes with terminal route lengths set such that the distance from the airport to UAL's first enroute fix approximates actual distance currently flown
VOR C - used for enroute wind mile comparison with RNAV	VOR A route corresponding to selected VOR B route (in most, but not all cases, the shortest wind mile VOR A route was the same as the shortest wind mile VOR B route)
UAL RNAV	UAL designed RNAV weather routes - great circle plus family of "concentric footballs"
SCI/NAFEC	SCI modification of NAFEC 429 airport pair structure routes to approximate UAL "footballs"
FAA/NAFEC	FAA modification of NAFEC 429 airport pair structure routes to encompass VOR weather routes
FAA/Direct - not used in SCI/FAA/NAFEC since another RNAV route was always equal or better	FAA designed structure encompassing wider excursions from the great circle than other structures, and providing for "S" shaped routes
SCI/FAA/NAFEC	Composite of SCI/NAFEC and FAA/NAFEC on an airport pair basis, utilizing best (shortest wind miles) of structures over entire sample period
Pre-planned	Composite (union) of all routes of all RNAV plus VOR A structures

and due to slight differences in definition of the terminal center points.

Table 3.12 presents the average enroute wind miles of the shortest ground mile routes ("preferred" routes) and the average enroute wind miles of the daily selected shortest wind mile routes ("best" routes) over the 39 day sample period.

Table 3.13 presents the average shortest ground mile and wind mile route RNAV benefit over the 39 day sample period, the RNAV benefit of the shortest RNAV vs. shortest VOR route in the NAFEC analysis and the average RNAV benefit when comparing the traffic weighted average of traffic distributed over RNAV routes and over VOR routes between the same airport pairs in the NAFEC analysis.

Columns 1, 2 and 3 of Table 3.13 present ground mile benefit, wind mile increment, and total benefit of the shortest ground mile routes. Column 4 presents the ground mile benefit of the shortest ground mile routes, and is the same as Column 1 except for computer rounding differences. Column 5 is the increment between shortest ground mile benefit and total ground mile plus wind mile benefit on the selected route which is given in Column 6.

The CLE-MIA, MIA-CLE and SEA-JFK airport pairs were excluded from Table 3.13, since they were not a part of the NAFEC 429 pair route structure analysis. The weather route analysis benefits in Table 3.13 are based on a comparison of the best routes from all the RNAV structures over the sample period ("pre-planned"). Tables of individual airport pair benefits from which Table 3.13 was compiled are included in Appendix C, together with day by day plots of wind miles on each of the simulated routes. Although the "pre-planned" route structure is a composite of all the route structures used in the analysis, and was originally intended to be representative of a pre-planned direct structure, the number of routes actually selected was not as large as anticipated.

Table 3.14 lists the number of routes available and selected in each of the structures, including the "pre-planned". Although a detailed analysis of the interaction of the selected "pre-planned" routes between each airport pair was not performed, it can be seen that the number of selected routes is small enough to indicate that they could form the basis of a charted structure (rather than pre-planned) which could be expected to yield similar benefits. The relatively small number of routes selected is attributed to the fact that all selected routes were those closer to the "center" great circle route, and the routes on the periphery of each structure were not selected. A more accurate approximation of a pre-planned direct structure would have been a more fine-grained definition of additional routes within the periphery of the structures defined by those routes actually selected in the weather route analysis.

As stated earlier in this section, two primary factors are of concern in the analysis and interpretation of the results of this study. The benefits available through RNAV when capacity and traffic flow considerations do not preclude selection of either the shortest wind mile VOR or the shortest wind mile RNAV route are represented by column 6 of Table 3.13, which yields an average route mile benefit of 0.92% based on the NAFEC analysis traffic sample.

TABLE 3.11

Route Structure Summary Data
Shortest Ground Mile Route/Ground Mile Output
Route Structure

AP PAIR	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
ORD DEN	783.9 (.08)	783.8 (.04)	783.8 (.06)	783.8 (.06)	784.0 (.09)	783.8 (.09)	784.0 (.09)
DEN ORD	784.8 (.19)	786.8 (.45)	788.3 (.63)	788.3 (.63)	790.0 (.85)	784.8 (.19)	790.0 (.85)
ORD LAX	1510.0 (.06)	1509.6 (.03)	1514.4 (.35)	1509.6 (.03)	1517.0 (.52)	1509.6 (.03)	1517.0 (.52)
LAX ORD	1510.6 (.10)	1516.3 (.48)	1509.6 (.03)	1509.6 (.03)	1524.0 (.99)	1509.6 (.03)	1524.0 (.99)
EWR ORD	638.1 (.40)	640.3 (.74)	640.7 (.81)	640.3 (.74)	637.0 (.22)	637.0 (.22)	637.0 (.22)
ORD EWR	636.1 (.08)	636.8 (.20)	636.1 (.08)	636.1 (.08)	636.1 (.08)	635.0 (-.09)	636.1 (.08)
IAD LAX	2005.9 (.25)	2004.2 (.16)	2019.1 (.90)	2019.1 (.90)	2006.9 (.30)	2001.5 (.02)	2006.9 (.30)
LAX IAD	2004.0 (.16)	2004.9 (.20)	2011.5 (.52)	2004.9 (.20)	2016.0 (.75)	2004.1 (.16)	2016.0 (.75)
MIA CLE	939.1 (.08)	944.1 (.60)	944.8 (.68)	944.1 (.60)	949.0 (1.13)	939.1 (.08)	949.0 (1.13)
CLE MIA	940.5 (.22)	944.5 (.65)	945.0 (.71)	944.5 (.65)	950.0 (1.24)	940.5 (.22)	950.0 (1.24)
JFK SEA	2098.0 (.10)	2099.2 (.16)	2099.6 (.18)	2099.2 (.16)	2118.2 (1.10)	2098.0 (.10)	2118.9 (1.10)
SEA JFK	2096.4 (.02)	2099.4 (.17)	2097.8 (.09)	2097.8 (.09)	2126.8 (1.47)	2096.4 (.02)	2126.8 (1.47)
AVERAGE	1329.0 (.13)	1330.8 (.27)	1332.6 (.40)	1331.4 (.32)	1338.0 (.81)	1328.3 (.08)	1338.0 (.81)

TABLE 3.12

Route Structure Summary Data

WIND MILE RESULTS: SHORTEST GROUND MILE ROUTE AND SELECTED WEATHER ROUTES

Data Based on Runs 1 through 39

AP PAIR	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
ORD DEN	871.8 871.3	870.4 870.4	871.3 871.1	870.4 870.4	874.4 870.9	870.4 867.6	874.4 872.5
DEN ORD	721.6 721.6	723.5 723.5	724.0 721.8	724.0 721.8	730.1 728.1	721.6 720.6	730.1 728.9
ORD LAX	1694.6 1672.2	1691.4 1673.4	1703.4 1676.4	1691.4 1673.4	1717.9 1683.6	1691.4 1669.5	1717.0 1688.7
LAX ORD	1372.8 1366.6	1382.8 1368.2	1372.5 1365.7	1372.5 1365.7	1389.2 1372.8	1372.5 1364.5	1389.2 1374.5
EWR ORD	723.6 720.0	727.2 724.4	726.8 725.0	727.2 724.4	728.5 725.7	728.5 719.5	728.5 727.9
ORD EWR	577.4 577.4	577.2 577.2	577.7 576.1	577.7 576.1	577.7 577.7	576.9 575.7	577.7 577.7
IAD LAX	2336.5 2287.9	2333.8 2290.7	2300.1 2288.9	2300.1 2288.9	2323.6 2303.9	2312.5 2275.4	2323.6 2311.1
LAX IAD	1777.4 1773.5	1773.5 1771.1	1783.2 1778.3	1773.5 1771.1	1784.3 1781.4	1777.4 1768.3	1784.3 1781.4
MIA CLE	982.1 982.1	982.1 982.0	985.5 985.5	982.1 982.0	986.4 986.4	982.1 980.4	986.4 986.4
CLE MIA	923.8 923.8	921.3 919.7	921.9 921.7	921.3 919.7	943.0 943.0	923.8 919.0	943.0 943.0
JFK SEA	2266.6 2251.0	2273.3 2253.8	2264.6 2254.6	2273.3 2253.8	2297.5 2269.3	2266.6 2247.6	2247.5 2269.4
SEA JFK	1985.0 1976.9	1985.4 1979.8	1985.9 1977.9	1985.9 1977.9	2009.5 1995.2	1985.0 1974.5	2009.5 2005.2
AVERAGE	1352.8 1343.7	1353.5 1344.5	1351.4 1345.2	1349.9 1344.6	1363.5 1353.2	1350.7 1340.2	1363.5 1355.6

Table 3.13 Comparison of RNAV Benefits from Weather Route Analysis and NAFEC Analysis

	weather route analysis shortest ground mile route average % RNAV benefit over VOR			weather route analysis shortest wind mile route average % RNAV benefit over VOR			NAFEC Analysis ground mile benefit % RNAV benefit over VOR	
Airport	(1) ground mile benefit	(2) wind mile increment	(3) total benefit	(4) ground mile benefit	(5) wind mile increment	(6) total benefit	(7) shortest routes*	(8) traffic weighted average of distributed routes
ORD-DEN	.02	.43	.45	.02	.54	.56	0	.50
DEN-ORD	.71	.45	1.16	.72	.42	1.14	.66	.66**
ORD-LAX	.45	1.11	1.54	.44	.70	1.14	.50	.97
LAX-ORD	1.04	.17	1.21	1.05	-.32	.73	1.43	1.50
ORD-EWR	.19	-.06	.13	.19	.15	.34	0	.37
EWR-ORD	0	0	0	0	1.15	1.15	3.20	3.20**
IAD-LAX	.23	.25	.48	.23	1.31	1.55	3.13	3.13**
LAX IAD	.67	-.28	.39	.67	.07	.74	1.51	1.51**
JFK SEA	.91	.43	1.34	.92	.04	.96	.63	.63**

*on which traffic was placed

**all traffic placed on a single VOR route and shortest RNAV route

Table 3.14
NUMBER OF ROUTES AVAILABLE/NUMBER OF ROUTES USED
39 DAY WEATHER SAMPLES

AIRPORT PAIR	ROUTE STRUCUTURE					
	UAL/RNAV	SCI/NAFEC	FAA/NAFEC	FAA/DIRECT	VOR A	PRE-PLANNED**
ORD-DEN	5.0/2	5.0/2	10.0/3	20.0/4	5.0/3	45.0/8
DEN-ORD	5.0/1	5.0/1	10.0/2	20.0/2	5.0/2	45.0/6
ORD-LAX	7.0/3	7.0/3	10.0/3	20.0/4	11.0/4	55.0/10
LAX-ORD	7.0/3	7.0/3	10.0/3	20.0/2	9.0/2	53.0/7
EWR-ORD	4.0/2	4.0/4	9.0/3	11.0/2	3.0/2	31.0/5
ORD-EWR	3.0/1	3.0/1	10.0/3	11.0/2	3.0/1	30.0/6
IAD-LAX	9.0/6	9.0/6	10.0/5	20.0/9	12.0/5	60.0/11
LAX-IAD	9.0/5	9.0/3	10.0/5	20.0/5	9.0/4	57.0/11
MIA-CLE	3.0/1	3.0/2	10.0/2	16.0/3	3.0/1	35.0/5
CLE-MIA	3.0/1	3.0/2	10.0/2	16.0/3	3.0/1	35.0/5
JFK-SEA	9.0/5	8.0/5	10.0/5	20.0/9	14.0/3	62.0/10
SEA-JFK	9.0/4	9.0/5	10.0/5	20.0/9	9.0/5	57.0/9
AVERAGE	6.1/2.8	6.1/ 3.1	9.9/3.4	17.8/ 4.5	7.2/ 2.8	47.1/ 7.7
TOTAL	73.0/34	73.0/37	119.0/41	214.0/54	86.0/33	565.0/93
RATIO OF NO. ROUTES USED TO NO. AVAIL.	.47	.51	.34	.25	.39	.16

** The pre-planned structure is the aggregation of all routes from each structure.

In comparing the ground mile benefit of the shortest ground mile route in the weather analysis (Column 1 of Table 3.13) with the ground mile benefit of the shortest routes on which traffic was placed in the NAFEC study (Column 7), it can be seen that in six cases the benefits are comparable (ORD-DEN, DEN-ORD, ORD-LAX, LAX-ORD, ORD-EWR and JFK-SEA). The benefits are also comparable when comparing selected weather route ground mile benefits (Column 4) with Column 7. In the other three cases the benefits differ enough to warrant further investigation (EWR-ORD, IAD-LAX, and LAX-IAD). In each of these cases traffic was placed on only one VOR and one RNAV route in the NAFEC analysis, and it is important to determine if the individual VOR routes were the shortest ground mile routes, which differed markedly from the shortest RNAV routes due to traffic flow peculiarities of the VOR structure, or if they were selected for wind mile optimization. The EWR-ORD VOR traffic utilized the preferred route published in Part 4 of the Airman's Information Manual for all 20 flights in the NAFEC analysis, and the route assignment can be considered to be for traffic flow purposes rather than requested weather routes. In the LAX-IAD case, all 7 flights were placed on a northerly routing (J-146, J-64, J-30) and in the IAD-LAX case, all 7 flights were placed on an extreme southerly routing (J-42, J-46, J-78). It can therefore be assumed that these routes assignments were in accordance with requested weather routings in the traffic sample.

The large discrepancy between the ground mile benefits of RNAV over VOR in the EWR-ORD case between Columns 1 and 7 of Table 3.13 is due to the large difference between the preferred VOR route for traffic flow and the shortest VOR route. In the case of the NAFEC RNAV structure, bi-directional traffic flow can be accommodated between these airport pairs with high traffic density, without the necessity of unduly increasing route length in one direction, as is the case in the VOR structure. The RNAV structure can therefore provide more flexibility, in cases like EWR-ORD, in accommodating high density bidirectional traffic and in allowing the selection of routes which optimize wind miles rather than constraining traffic to long ground mile routes which may in turn be also less desirable from a wind viewpoint. The wind mile increment over ground miles of the benefit on the shortest wind route between EWR and ORD (Column 5 of Table 3.13) would therefore tend to be additive to the ground mile benefit which allows selection of that route in the first place (Column 7).

On the other hand, the discrepancy between Column 1 and Column 7 for IAD-LAX and LAX-IAD is due to selection of minimum ground mile routes in one case (Column 1) for both VOR and RNAV, and selection of minimum ground miles for RNAV and minimum wind miles (longer ground miles) for VOR in the other case (Column 7). The RNAV benefit given in Column 7 and 8 is therefore overstated for these airport pairs. In these cases the actual RNAV benefit is more accurately represented by the total benefit over the shortest wind mile route (Column 6). The NAFEC 429 airport pair RNAV structure which was used in the no wind, traffic distributed RNAV vs. VOR route mile analysis may be characterized as consisting of two groups of airport pairs together with their connecting RNAV routes:

(1) Airport pairs between which VOR traffic is currently routed without concern for wind effects. This traffic included that on minimum ground mile routes, on ATC published preferred routes which in many cases are much longer than the minimum ground mile route, and traffic placed on other than minimum ground mile routes on an ad hoc basis for the purpose of traffic control.

(2) Airport pairs between which VOR traffic is currently routed primarily in response to requested routings established to minimize wind miles.

In both cases traffic is currently distributed over one or more VOR routes between each airport pair, and over one or more RNAV routes between each airport pair for benefit comparison.

Since the NAFEC analysis was reasonably realistic in terms of traffic distribution, it is required only to separate the 429 airport pairs into the two groupings described above in order to calibrate the second group with the results of the weather route analysis. In order to perform this separation, it was arbitrarily assumed that any airport pair separated by a great circle enroute distance of more than 500 miles in the NAFEC structure had traffic distributed over VOR routes between these airport pairs on the basis of minimum wind miles. An exception was made if a published ATC preferred route existed for that airport pair and the great circle distance was less than 800 miles (13 airport pairs). An exception was also made if traffic was distributed over more than one VOR route and the great circle distance was less than 800 miles (3 airport pairs). In these cases, traffic was allowed to remain on the routes used in the NAFEC analysis. A total of 203 airport pairs out of the 429 met these criteria. It was assumed that, for routes of less than 500 miles, the characteristics of the VOR route structure, coupled with the distribution of traffic over more than one route per airport pair, were dominant over wind effects with respect to the realization of benefits on RNAV routes. This assumption was validated by an examination of the ground mile benefits on these shorter routes in the NAFEC analysis which showed that the average ground mile benefits on the shorter routes were three times larger than the wind mile increments experienced in the weather route simulation. The total flight mile benefit for each of these routes in the NAFEC analysis was then adjusted to represent an average wind mile benefit as determined below.

The 39 day average RNAV percent route structure combination benefit for each two way airport pair relative to the VOR C structure with the exception of the CLE-MIA airport pair whose results were significantly affected by computational anomalies, appear to be a reasonably well behaved linear function of the great circle distances.

Lines were fit through these data points utilizing the least squares technique, the results of which are summarized in Table 3.15.

TABLE 3.15

PARAMETERS FOR THE RNAV PERCENT BENEFIT EQUATION

$$P = a \cdot G + b$$

where G = Great Circle Distance (terminal center to terminal center)
P = RNAV Route Length Benefit
In Percent of VOR Distance

ROUTE STRUCTURE	RELATIVE to VOR C	
	a	b
Pre-Planned	0.000296	0.569
UAL/RNAV	0.000273	0.363
SCI/NAFEC	0.000361	0.123
FAA/NAFEC	0.000271	0.251
SCI/FAA/NAFEC	0.000316	0.264

Using the benefit equation from Table 3.15 for the "pre-planned" (representative of optimum charted) structure, the flight mile benefit for each of the 203 airport pairs as follows:

total VOR flight miles between 429 airport pairs	2,674,014
total RNAV flight miles between 429 airport pairs	2,611,220
flight mile benefit from NAFEC analysis	62,794
adjusted flight mile benefit from 203 airport pairs	-15,042
adjusted flight mile benefit over 429 airport pairs	47,752

RNAV flight mile (traffic weighted) benefit relative to VOR = 1.79%

The weather route calibration of the NAFEC no-wind analysis is conservative (in favor of VOR) for two reasons:

(1) It does not consider real world impromptu deviations from optimum weather routings, larger than corresponding RNAV routing deviations, which are currently required for traffic control, or due to traffic density.

(2) It does not include the additional wind mile benefits available through the ability to select an RNAV route which is more favorably oriented than a current VOR preferred route.

3.2.2 Restricted Area Analysis

All restricted and warning areas which would potentially affect the high altitude enroute RNAV structure were identified in the Federal Register, Part 73, "Special Use Airspace". These areas were then plotted on a projection of the NAFEC 429 airport pair RNAV route structure. All route segments impinging upon, or in close proximity to, the plotted restricted areas were then identified and were plotted on a high altitude enroute airways chart for verification. A section of the high altitude airways chart showing RNAV route segments crossing restricted areas is illustrated in Figure 3.10.

The airport pairs associated with each route segment which violated a restricted (or warning) area were identified from a computer listing provided by NAFEC [4]. A listing of restricted and warning areas which affect the NAFEC structure and the corresponding affected route segments is given in Table 3.16. The high altitude route structure airport pairs which utilize the affected route segments are given in Table 3.17.

Table 3.16
NAFEC Design Route Segments Affected by Restricted Areas

Restricted/warning Area	Route Segments Affected	
R2306	345G	379W 379E 345B
R2308	345G	379W 379E
R2501	007E	010E
R2502	003W	380C
R2505	380C	
R2507	345G	F414 379W 345B
R2508	400A	256W 446A 155G 177A
	380C	400B
R2510	379W	
R2515	177A	177P
R2521	345B	F414
R2524	177A	177P 380C
R3005	420A	
R4806	155G	177A 177P
R4807	155G	449A
R4808	155G	C340
R4809	449A	
R5103	174C	
R5107	174C	034A 217W 217E
R5111	217W	217E
R5503	2250	3890 318A 3700 3820 453D
R5504	2250	3890
R6402	014H	014P 005A
R6404	365A	
R6405	014H	005A
R6406	258A	
R6407	014P	
R6714	298C	
R6903	258B	304A
W106	117A	
W107	117A	006A 006P
W122	117A	006B 051B
W132	126A	
W151	367A	
W157	126A	
W158	006C	051B 126A 126B
W177	126A	

TABLE 3.17 ROUTE SEGMENTS IMPINGING ON RESTRICTED/ WARNING AREAS AND CORRESPONDING AIRPORT PAIRS

Route Segment	Airport Pairs
003W	BURLAS LAXBUR LAXMSP ONTLAS
005A	DTWSFO OAKORD PHLSFO SFODTW SFOMDW SFOORD SFOPHL SJCORD
006A	BDLMIA FLLEWR FLLJFK MIABDL MIAEWR MIAJFK MIALGA
006B	BDLMIA EWRFLL FLLEWR FLLJFK JFKFLL JFKMIA MIABDL MIAEWR MIAJFK MIALGA
006C	BDLMIA EWRFLL JFKFLL JFKMIA
006P	EWRFLL JFKFLL JFKMIA JFKORF LGAORF
007E	LAXCLE LAXMDW LAXORD ONTORD
010E	LAXBAL LAXEWR LAXEWR2 LAXIAD LAXJFK LAXJFK2 LAXLGA LAXLGA2 LAXMKC LAXPHL LAXSTL
014H	EWRSFO JKFOAK JFKSFO JFKSJC LGASFO MDWSFO OAKJFK ORDOAK ORDSFO ORDSJC SFOEWR SFOJFK SFOLGA SFOORD2 SJCJFK
014P	JFKSFO3 ORDSFO3 SFOJFK3
034A	DALLAX DALPHX LAXDAL LAXMSY MSYLAX PHXDAL
051B	EWRMIA FLLPHL JFKPBI LGAMIA LGAPBI MIAPHL PBIJFK PBILGA PHLFLL PHLMIA
117A	BOSFLL BOSMIA FLLBOS MIABOS
126A	BALMIA DCAMIA IADMIA MIABAL MIADCA MIAIAD
126B	BALMIA DCAMIA IADMIA
155G	ABQSFO DALSFO MIASFO SFOABQ SFODAL SFOMIA
174C	IAHLAX IAHPHX LAXIAH LAXMIA MIALAX PHXIAH
177A	LAXSLC SLCLAX
177P	LAXSLC
217E	ABQELP
217W	ELPABQ
2250	ATLDTW DTWATL
256W	BURRNO LAXPDX LAXRNO LAXSEA
258A	BOSSFO SFOBOS
258B	BOSSFO SFOBOS
298C	DENSEA SEADEN
304A	BALSEA DCAMSP DTWMSP IADSEA MSPDCA MSPDTW SEABAL SEAIAD
318A	GSOORD ORDGSO
345B	ELPLAX SATLAX TUSLAX
345G	LAXDAL LAXELP LAXIAH LAXMIA LAXMSP LAXPHX LAXSAT LAXTUS ONTPHX SANPHX
365A	MSPSFO SFOMSP
367A	MSYTPA TPAMSY
3700	ORDRDU RDUORD
379E	SANPHX
379W	PHXSAN
380C	PHXSFO SFOPHX
3820	PITSDF SDFPIT
3890	DTWTPA TPADTW
400A	IAHSFO SFOIAH
400B	IAHSFO SFOIAH
420A	CMHMIA DTWMIA MIACMH MIADTW
446A	PSPSFO SFOPSP
449A	ABQMCC MCCABQ
453A	BOSDAL DALBOS
C340	RNOLAS
F414	SANJFK SANORD

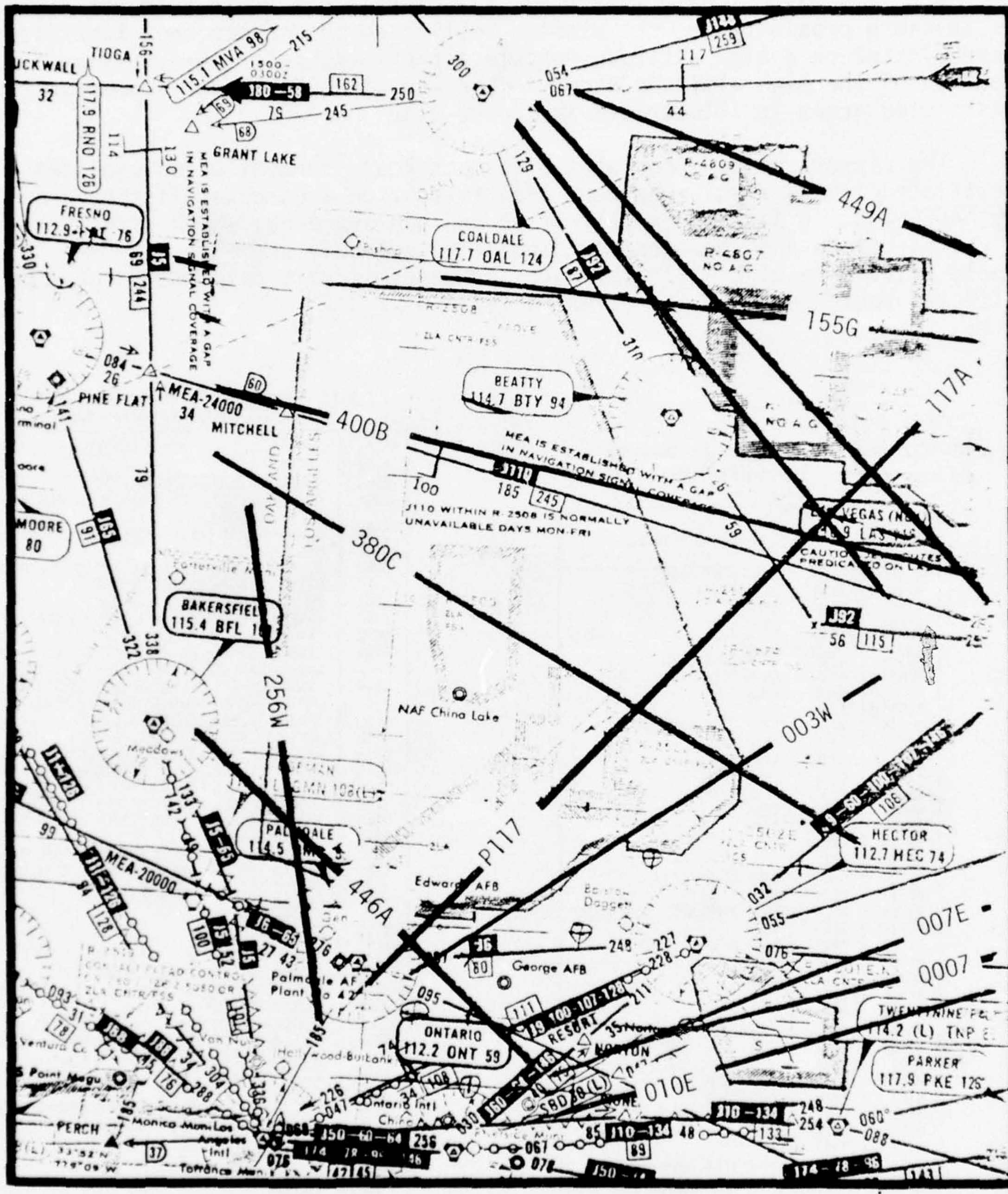


Figure 3.10 NAFEC High Altitude Route Structure-Route Segments Crossing Restricted Areas

The modification of the NAFEC route length analysis described in Section 3.2.1.3 recognized the RNAV savings in route length which would be available through the approximation of desired weather paths by RNAV routes rather than VOR routes. These RNAV benefits represent the average differences in path length between RNAV and VOR in traversing a desired curved path (in that case a "weather route") which is represented by a series of great circle segments which closely approximate the desired path in the RNAV case, and a series of VOR segments which less accurately approximate the desired path in the VOR case. This RNAV benefit was found to be a linear function of a great circle distance.

In order to calibrate the NAFEC route length analysis for restricted area effects, it was assumed that "curved paths" necessary to avoid restricted areas would be analogous to the "curved paths" representing weather routes, and that the same route length dependent benefits would apply. As in the weather route calibration, airport pairs separated by more than 500 miles were assigned RNAV benefits in accordance with Table 3.15. All airport pairs separated by less than 500 miles whose connecting route penetrated a restricted area were assigned zero RNAV benefit. The benefit over the 429 airport pair structures was then computed as follows:

Total VOR flight miles between
429 airport pairs from
NAFEC analysis --------------2,674,014

Flight mile benefit from
NAFEC analysis (RNAV vs VOR)-- 62,794
RNAV benefit over VOR = 2.35%

Flight mile benefit from weather route
calibration of NAFEC analysis (section 3.2.1) ---------47,752
RNAV benefit over VOR = 1.79% for following assumptions:

- VOR routes do not violate restricted areas
- RNAV routes not constrained by restricted areas
- Airport pairs separated by distances of 500 mi or less, and by 800 mi or less if VOR route is a preferred route, assigned benefit from NAFEC analysis
- Airport pairs separated by more than 800 miles, or more than 500 miles if VOR route is not a preferred route, assigned benefit based on weather route analysis

Flight mile benefit from weather route and restricted area calibration of NAFEC analysis (Section 3.2.2) ---43,092

RNAV benefit over VOR = 1.61% for following assumptions:

- VOR routes do not violate restricted areas
- RNAV routes do not violate restricted areas
- Airport pairs separated by distance of 500 mile or less:
  - Assigned zero benefit if RNAV route violates a restricted area
  - Assigned NAFEC derived benefit if RNAV route does not violate a restricted area
- Airport pairs separated by distance of 500 to 800 miles:
  - Assigned benefit derived from weather route analysis if RNAV route violates a restricted area or VOR route is not a preferred route
  - Assigned benefit derived from NAFEC analysis if RNAV route does not violate a restricted area and VOR route is a preferred route
- Airport pairs separated by distance of greater than 800 miles assigned benefit derived from weather route analysis

In summary, a conservative estimate of traffic weighted average flight mile in a high altitude enroute RNAV structure, compared with the current VOR jet route structure, is 1.61%. This estimate includes the effects of wind on selected weather routes, the effects of real world traffic distribution, and the assumption that the RNAV structure will be constrained by existing restricted areas, and is based on an RNAV structure capable of accommodating 92% of the estimated 1977 traffic on an average day, with minor extensions to include airports in close proximity to the simulated structure. A listing of the airport pairs utilized in the NAFEC analysis, calibrated for both weather route and restricted area effects is given in Table 3.18. In cases where route mile benefits are shown but flight mile benefits are zero, no traffic was applied to that airport pair in the NAFEC analysis. It should be emphasized that the NAFEC structure used in this analysis has not been optimized, and that some increase in benefits could be expected in a properly optimized structure.

TABLE 3.18
ROUTE MILE AND FLIGHT MILE SAVINGS: RNAV OVER VOR

AIRPORT PAIR FROM	TO	VOR ROUTE MILES	ROUTE MILES VOR -RNAV	FLIGHT MILES VOR -RNAV
ABE	PIT	140	5	22
ABQ	DTW	434	32	194
ABQ	DEN	211	6	30
ABQ	ELP	124	0	0
ABQ	LAX	485	-3	-25
ABQ	MCC	720	5	5
ABQ	MDW	877	7	0
ABQ	PHX	197	-2	-8
ABQ	TUS	225	35	106
ALB	BUF	131	2	9
AMA	DTW	184	-1	0
ATL	BAL	388	14	88
ATL	BNA	98	1	11
ATL	BOS	770	6	54
ATL	BUF	535	4	4
ATL	CAE	91	14	114
ATL	CLE	414	19	98
ATL	CLT	116	8	101
ATL	DFW	555	1	23
ATL	DCA	388	3	42
ATL	DTW	440	0	0
ATL	EWR	585	4	38
ATL	GSO	178	0	3
ATL	JAX	146	-6	-104
ATL	JFK	691	4	38
ATL	LAX	1642	17	169
ATL	LGA	567	4	46
ATL	MEM	217	12	128
ATL	MIA	470	41	671
ATL	MSY	288	4	69
ATL	ORD	424	-2	-38
ATL	PBI	389	-39	-236
ATL	PHL	506	13	117
ATL	PIT	376	5	27
ATL	SAV	116	18	113
ATL	SDF	190	-3	-8
ATL	SFO	1800	20	98
ATL	STL	360	29	176
ATL	TPA	277	11	176
AUS	DFW	82	17	153
AUS	ELP	371	0	2
BAL	ATL	387	9	68
BAL	BOS	261	17	189
BAL	CLE	188	26	52
BAL	DFW	1006	8	16
BAL	DTW	266	19	38
BAL	LAX	1924	21	87
BAL	OMA	824	47	0

AIRPORT PAIR FROM	TO	VOR ROUTE MILES	ROUTE MILES VOR -RNAV	FLIGHT MILES VOR -RNAV
BAL	ORD	436	22	180
BAL	PIT	73	-20	-40
BAL	STL	534	10	10
BDL	DCA	187	23	117
BDL	ORD	589	-2	-27
BDL	PIT	274	7	71
BHM	JAN	107	12	49
BHM	ORD	434	30	120
BKF	ADW	1228	21	87
BNA	ATL	100	4	28
BNA	DCA	413	17	68
BNA	MEM	87	0	7
BNA	ORD	258	6	25
BNA	PHL	515	11	23
BNA	PIT	341	28	57
BOI	PDX	216	7	28
BOI	SLC	164	0	2
BOS	ATL	748	5	54
BOS	BAL	243	-1	-17
BOS	BUF	256	0	-1
BOS	CLE	418	16	97
BOS	DFW	1316	12	12
BOS	DCA	244	0	-21
BOS	JFK	76	17	87
BOS	LAX	2214	27	133
BOS	MIA	1030	0	0
BOS	ORD	660	-4	-94
BOS	PHL	195	35	637
BOS	PIT	353	25	201
BOS	ROC	209	0	-3
BOS	SFO	2299	28	113
BOS	STL	881	7	28
BUF	ALB	134	1	8
BUF	ATL	551	4	4
BUF	BOS	259	-1	-4
BUF	DTW	127	3	19
BUF	EWR	182	26	133
BUF	ORD	314	0	-6
BUF	PHL	191	38	38
BUR	LAS	102	0	0
BUR	OAK	179	0	0
BUR	RNO	249	0	0
BUR	SFO	199	20	208
BUR	SUC	190	8	81
CAE	ATL	111	34	273
CAK	ORD	226	49	147
CHS	DCA	294	3	6
CLE	ATL	414	22	111

AIRPORT PAIR FROM	TO	VOR ROUTE MILES	ROUTE MILES VOR -RNAV	FLIGHT MILES VOR -RNAV
CLE	BAL	168	1	2
CLE	BDL	348	10	72
CLE	BOS	404	-1	-8
CLE	DFW	839	7	20
CLE	DCA	202	35	282
CLE	EWR	259	2	13
CLE	IAD	202	35	35
CLE	IND	146	7	23
CLE	JFK	267	9	49
CLE	JAX	1668	18	128
CLE	LGA	258	-7	-87
CLE	MDW	184	7	28
CLE	MKE	204	4	14
CLE	ORD	185	8	139
CLE	PHL	237	7	59
CLE	STL	345	10	74
CLE	ATL	108	-1	-17
CLE	DCA	230	39	117
CLE	EWR	381	16	67
CLT	JFK	390	25	51
CLT	ORD	428	10	64
CLT	PHL	312	12	37
CLT	PIT	240	10	21
CMH	DCA	179	4	18
CMH	LGA	318	10	54
CMH	MDW	168	14	0
COS	MKC	394	13	13
DFW	ABQ	410	3	23
DFW	AMA	185	0	0
DFW	ATL	563	4	67
DFW	AUS	67	-1	-15
DFW	BAL	980	17	35
DFW	BNA	480	22	0
DFW	CLE	835	7	20
DFW	DEN	505	31	250
DFW	ELP	396	4	28
DFW	IAD	955	8	57
DFW	JFK	1186	10	61
DFW	LAX	999	9	142
DFW	LBB	170	16	150
DFW	LGA	1158	47	190
DFW	LIT	196	18	111
DFW	MAF	179	-2	-20
DFW	MEM	304	19	159
DFW	MKC	315	2	19
DFW	MSY	302	-4	-59
DFW	OKC	67	-1	-14
DFW	ORD	600	5	64

AIRPORT PAIR FROM	TO	VOR ROUTE MILES	ROUTE MILES VOR -RNAV	FLIGHT MILES VOR -RNAV
DFW	PHX	713	0	0
DFW	SAT	127	8	96
DFW	SFO	1177	11	123
DFW	STL	400	9	78
DAY	BAL	378	41	0
DAY	JFK	405	33	0
DAY	TEB	381	9	0
DAY	ATL	382	8	99
DCA	BNA	392	1	7
DCA	BOS	261	17	568
DCA	BUF	168	22	133
DCA	CHS	289	-1	-4
DCA	CLE	188	26	208
DCA	CLT	206	12	48
DCA	CMA	207	27	138
DCA	DAY	260	21	86
DCA	DTW	266	19	171
DCA	JAX	465	7	21
DCA	JFK	100	-1	0
DCA	LGA	66	-3	-24
DCA	MDW	455	42	126
DCA	MEM	568	2	7
DCA	MIA	718	5	62
DCA	MKE	467	20	61
DCA	MSP	728	6	28
DCA	ORD	455	42	888
DCA	PIT	93	0	0
DCA	SDF	320	7	23
DCA	STL	544	4	31
DCA	TYS	287	2	14
DEN	ABQ	206	-1	-5
DEN	BOI	469	-5	-15
DEN	DFW	490	15	137
DEN	DTW	913	4	23
DEN	IAD	1214	11	33
DEN	ICT	309	23	118
DEN	JFK	1323	6	63
DEN	LAS	451	5	40
DEN	LAX	636	3	83
DEN	LGA	1323	10	0
DEN	MKC	397	14	141
DEN	MSP	515	0	5
DEN	OMA	338	5	25
DEN	ORD	688	4	90
DEN	PDX	776	5	34
DEN	PHX	432	5	41
DEN	SEA	808	6	45
DEN	SFO	726	4	56

TABLE 3.18
(Cont'd.)

AIRPORT PAIR FROM	TO	VOR ROUTE MILES	ROUTE MILES VOR -RNAV	FLIGHT MILES VOR -RNAV
DEN	SJC	726	4	4
DEN	SLC	245	2	31
DEN	STL	599	5	27
DET	PHL	319	11	0
DSM	LAX	1164	9	9
DSM	MSP	111	0	0
DSM	ORD	161	0	0
DTW	ATL	449	0	0
DTW	BAL	248	0	1
DTW	BDL	393	1	3
DTW	BOS	469	0	0
DTW	BUF	163	44	220
DTW	DCA	285	37	338
DTW	DEN	899	-5	-17
DTW	EWR	333	-13	-66
DTW	LAX	1663	12	122
DTW	LGA	351	4	64
DTW	MDW	128	23	184
DTW	MKC	466	-5	-17
DTW	MKC	122	0	-7
DTW	MSP	384	0	0
DTW	ORD	101	-4	-97
DTW	PHL	320	11	92
DTW	PIT	85	-1	-7
DTW	SDF	182	5	22
DTW	SFO	1736	18	93
DTW	STL	327	26	131
DTW	SYR	255	19	57
ELP	ABQ	124	0	0
ELP	DAL	356	1	42
ELP	LAX	508	0	0
ELP	LSV	428	10	32
ELP	MAF	128	3	15
ELP	PHX	237	25	75
ELP	SAT	342	0	0
ELP	TUS	145	0	3
EWR	ATL	569	4	38
EWR	BUF	146	-3	-19
EWR	CLE	268	8	50
EWR	CLT	377	6	27
EWR	DTW	338	1	8
EWR	FLL	868	7	36
EWR	GSO	301	4	22
EWR	IAD	60	0	0
FWR	IND	477	9	0
EWR	JAX	621	3	3
EWR	LAX	2034	0	0
EWR	MIA	856	7	48
EWR	ORD	531	17	344
EWR	PIT	193	4	43
EWR	ROC	121	7	0
EWR	SFO	2158	27	80
EWR	STL	675	5	5
EWR	TPA	811	7	13
FLL	BOS	1029	9	9
FLL	EWR	874	7	36
FLL	JFK	864	5	40
FLL	ORD	957	8	41
FLL	PHL	853	7	7
FLL	TPA	90	-4	-28
GEG	SFO	584	4	8
GSO	EWR	304	12	61
GSO	IAD	123	3	0
GSO	LGA	304	11	23
GSO	ORD	434	0	0
GSO	TEB	301	3	0
HOU	ORD	723	6	33
HPN	RCC	121	7	0
IAD	ATL	390	12	48
IAD	BOS	264	19	59
IAD	DAL	948	8	65
IAD	DEN	1220	12	34
IAD	DTW	266	18	18
IAD	EWR	99	-3	-27
IAD	JFK	100	-1	-10
IAD	LAX	1947	22	151
IAD	MSY	761	16	0
IAD	ORD	455	42	84
IAD	SEA	1943	22	22
IAD	SFO	2159	23	116
IAD	STL	536	12	12
ICT	DEN	284	-2	-16
ICT	MDW	411	1	0
ICT	MKC	73	0	-2
ICT	ORD	409	0	-3
IND	CLE	146	6	20
IND	EWR	489	20	0
IND	JFK	497	28	28
IND	MEM	248	6	31
IND	STL	109	0	-5
JAN	EHM	107	12	50
JAN	MEM	75	-1	-7
JAN	SHV	101	0	-1
JAX	ATL	148	2	34
JAX	DCA	462	7	28
JAX	EWR	626	4	4
JAX	JFK	634	5	19
JAX	MIA	203	0	2
JFK	ATL	572	18	156
JFK	BOS	106	50	254
JFK	CLE	273	13	67
JFK	DFW	1127	10	61
JFK	DAY	391	19	0
JFK	DCA	103	2	2
JFK	DEN	1406	13	78
JFK	DTW	338	1	9
JFK	FLL	888	7	50
JFK	IAD	104	3	21
JFK	IND	483	15	15
JFK	JAX	626	5	19
JFK	LAS	1888	21	105
JFK	LAX	2040	0	0
JFK	MIA	874	0	0
JFK	MKE	547	3	12
JFK	JSF	787	2	9
JFK	MSY	952	8	40
JFK	OAK	2165	27	0
JFK	ORD	558	4	62
JFK	PHX	1781	19	19
JFK	SAN	2041	24	72
JFK	SEA	2011	23	94
JFK	SFO	2165	25	485
JFK	SJC	2163	27	0
JFK	STL	681	5	10
JFK	TPA	789	6	0
LAS	BWR	102	0	1
LAS	DEN	458	6	42
LAS	JFK	1852	10	53
LAS	LAX	104	2	87
LAS	ONT	103	1	3
LAS	ORD	1233	12	163
LAS	PHX	140	9	79
LAS	RNO	235	0	0
LAS	SFO	293	0	0
LAS	SJC	295	0	0
LAS	SLC	239	6	54
LAS	SBQ	486	3	27
LAS	ATL	1594	10	107
LAX	BAL	1907	22	109
LAX	BOS	2180	26	132
LAX	CLE	1684	18	156
LAX	DEN	637	7	165
LAX	DSM	156	0	0
LAX	DFW	591	9	145
LAX	DTW	1619	15	138
LAX	ELP	513	0	0
LAX	EWR	2023	24	157
LAX	IAD	1913	24	152
LAX	JFK	2032	16	385
LAX	LAS	103	3	117
LAX	MIA	1937	23	113
LAX	MKC	1094	10	59
LAX	MSP	1241	12	59
LAX	MSY	1386	14	27
LAX	OAK	193	14	269
LAX	OKC	936	7	35
LAX	OMA	1057	9	28
LAX	ORD	1412	14	391
LAX	PDX	660	5	51
LAX	PHL	1995	14	115
LAX	PHX	208	0	-15
LAX	SEA	761	6	66
LAX	SFO	199	17	1454
LAX	SJC	192	9	137
LAX	SLC	425	0	0
LAX	SMF	236	6	113
LAX	STL	1304	12	74
LAX	TUS	288	0	0
LBB	DAL	170	10	102
LGA	ATL	560	4	42
LGA	BHM	654	5	30
LGA	BUF	146	-3	-27
LGA	CLE	270	10	109
LGA	CLT	387	16	66
LGA	DAY	385	13	83
LGA	DCA	105	4	35
LGA	DTW	338	1	-65
LGA	IAD	100	-1	-23
LGA	JAX	627	9	18
LGA	MIA	865	7	78
LGA	MKC	871	7	51
LGA	ORD	532	15	600
LGA	PBI	803	7	21
LGA	PIT	201	12	194
LGA	ROC	121	7	51
LGA	SDF	483	15	30
LGA	STL	675	5	47
LIT	DAL	179	4	29
LSV	ELP	483	64	257
LUK	ICT	483	0	0
MAF	DFW	178	-1	-8
MAF	DEN	429	31	94

TABLE 3.18
(Cont'd.)

AIRPORT PAIR FROM	TO	VOR ROUTE MILES	ROUTE MILES VOR -RNAV	FLIGHT MILES VOR -RNAV
MAF	ELP	126	1	7
MDW	CLE	183	-1	-4
MDW	CMH	168	14	0
MDW	DCA	453	34	104
MDW	DEN	683	-3	-7
MDW	DTW	110	8	58
MDW	HPN	542	14	0
MDW	MKC	252	0	1
MDW	MSP	201	11	47
MDW	SDF	147	0	3
MDW	STL	137	14	89
MEM	ATL	201	-1	-11
MEM	BHM	96	0	2
MEM	BNA	87	3	35
MEM	DFW	295	9	88
MEM	DCA	597	35	106
MEM	IND	243	0	0
MEM	JAN	75	-1	-5
MEM	LAX	1379	13	38
MEM	LGA	757	6	18
MEM	MSY	214	-4	-24
MEM	ORD	322	1	7
MEM	SHV	161	2	9
MEM	STL	132	4	69
MGM	MSY	161	9	46
MIA	ABQ	1448	66	0
MIA	ATL	453	23	453
MIA	BAL	762	6	23
MIA	BDL	977	9	34
MIA	BOS	1081	9	82
MIA	CMH	814	7	13
MIA	DFW	901	8	84
MIA	DCA	747	6	63
MIA	DTW	924	8	39
MIA	EWR	889	7	80
MIA	IAD	751	6	6
MIA	JFK	881	8	222
MIA	LAX	1937	13	81
MIA	LGA	892	7	80
MIA	MSY	509	2	19
MIA	ORD	959	8	74
MIA	PHL	820	7	66
MIA	PIT	811	6	26
MIA	SFO	2206	26	53
MIA	STL	861	7	35
MIA	TPA	90	-4	-88
MIA	DFW	326	11	106
MKC	DEN	397	3	33

AIRPORT PAIR FROM	TO	VOR ROUTE MILES	ROUTE MILES VOR -RNAV	FLIGHT MILES VOR -RNAV
MKC	EWR	883	7	7
MKC	ICT	73	-2	-17
MKC	LAX	1080	3	22
MKC	LGA	878	18	126
MKC	MSP	255	3	10
MKC	ORD	250	2	60
MKC	SFO	1211	12	23
MKC	STL	127	9	155
MKC	TUL	106	1	4
MKE	ATL	518	25	120
MKE	CLE	207	8	35
MKE	DCA	528	80	240
MKE	DEN	733	6	17
MKE	DTW	117	-1	-15
MKE	JFK	546	-3	-17
MKE	MSP	173	1	21
MKE	STL	213	18	36
MSP	DCA	742	6	34
MSP	DEN	538	4	23
MSP	DSM	111	0	0
MSP	DTW	446	0	0
MSP	FSD	81	-1	-11
MSP	JFK	795	0	1
MSP	LAX	1241	12	58
MSP	MDW	196	6	27
MSP	MKC	255	3	11
MSP	MKE	176	7	93
MSP	MSN	127	18	72
MSP	OMA	156	0	2
MSP	ORD	190	0	0
MSP	SEA	1134	3	10
MSP	SFO	1303	12	74
MSY	ATL	288	0	-5
MSY	BAL	763	6	18
MSY	DFW	304	4	58
MSY	JFK	961	8	40
MSY	LAX	1354	13	28
MSY	MEM	214	-2	-12
MSY	MIA	505	7	53
MSY	ORD	626	1	5
MSY	TPA	354	0	0
OAK	BUR	182	1	3
OAK	LAS	264	0	0
OAK	LAX	182	1	33
OKC	DEN	365	20	62
OKC	LAX	925	-3	-15
OMA	BAL	807	33	0
OMA	DEN	340	5	25

AIRPORT PAIR FROM	TO	VOR ROUTE MILES	ROUTE MILES VOR -RNAV	FLIGHT MILES VOR -RNAV
OMA	MSP	156	1	10
OMA	ORD	264	2	17
ONT	LAS	99	0	0
ONT	OAK	199	13	0
ONT	SFO	199	13	110
ONT	SJC	190	4	22
ORD	ABQ	882	7	29
ORD	ATL	435	17	278
ORD	BAL	447	29	261
ORD	BDL	598	18	235
ORD	BHM	409	3	10
ORD	BNA	254	1	9
ORD	BOS	656	-15	-334
ORD	BUF	349	39	358
ORD	CAK	230	45	91
ORD	CLE	181	-2	-41
ORD	CLT	443	20	123
ORD	OMH	168	14	102
ORD	DFW	622	19	288
ORD	DCA	444	25	539
ORD	DEN	683	4	67
ORD	DSM	159	2	16
ORD	DTW	103	1	20
ORD	EWR	516	-3	-38
ORD	FLL	960	8	49
ORD	HOU	736	5	32
ORD	ICT	419	5	20
ORD	JFK	518	0	14
ORD	LAS	1255	12	163
ORD	LAX	1409	10	0
ORD	LGA	519	1	49
ORD	MEM	323	-4	-34
ORD	MIA	953	8	81
ORD	MKC	251	0	0
ORD	MSP	212	23	644
ORD	OAK	1531	16	48
ORD	OMA	252	-4	-33
ORD	PHX	1423	12	48
ORD	PHL	526	28	519
ORD	PHX	1204	11	97
ORD	PIT	254	-2	-28
ORD	RDU	507	0	0
ORD	ROC	386	23	171
ORD	SAN	1400	3	19
ORD	SEA	1415	14	140
ORD	SFO	1513	16	421
ORD	SJC	1537	16	33
ORD	SLC	1007	9	70

AIRPORT PAIR FROM	TO	VOR ROUTE MILES	ROUTE MILES VOR -RNAV	FLIGHT MILES VOR -RNAV
ORD	STL	136	12	240
ORD	TPA	804	6	32
ORD	TUL	440	28	57
ORD	TUS	1175	11	43
ORF	JFK	160	-5	-10
ORF	LGA	157	-8	0
PBI	ATL	391	0	0
PBI	JFK	877	8	15
PBI	LGA	823	7	14
PDX	BOI	216	2	11
PDX	LAX	639	4	47
PDX	OAK	399	21	43
PDX	ORD	1415	-7	-39
PDX	SFO	399	21	215
PDX	SLC	466	0	0
PHL	ATL	500	9	81
PHL	BNA	510	10	32
PHL	BOS	208	43	823
PHL	BUF	210	53	53
PHL	CLE	230	-1	-9
PHL	CLT	329	21	64
PHL	DTW	326	14	128
PHL	LAX	2026	23	210
PHL	MIA	816	7	70
PHL	ORD	509	16	288
PHL	PIT	159	8	171
PHL	SFO	2133	25	101
PHL	STL	621	3	13
PHX	ABQ	200	0	-2
PHX	DFW	716	5	37
PHX	DEN	443	19	135
PHX	ELP	241	25	50
PHX	JFK	1799	17	34
PHX	LAS	140	5	42
PHX	LAX	208	3	64
PHX	MDW	1166	12	0
PHX	ORD	1163	11	108
PHX	SAN	192	0	0
PHX	STL	1012	2	8
PIT	ABE	131	3	12
PIT	ATL	388	19	96
PIT	BAL	94	2	4
PIT	BNA	345	30	91
PIT	BOS	372	24	218
PIT	CLT	235	3	7
PIT	DCA	104	7	85
PIT	EWR	210	29	324
PIT	FLL	810	17	0

TABLE 3.18
(Cont'd.)

AIRPORT PAIR FROM	AIRPORT PAIR TO	VOR ROUTE MILES	ROUTE MILES VOR -RNAV	FLIGHT MILES VOR -RNAV
PIT	LGA	185	4	68
PIT	MDW	267	10	54
PIT	MIA	809	6	26
PIT	ORD	267	10	217
PIT	PHL	144	-5	-117
PIT	SDF	209	0	0
PSF	SFO	274	0	0
RDU	ATL	223	2	15
RDU	ORD	489	0	0
RIC	LGA	146	0	1
RNO	LAS	219	0	0
RNO	LAX	259	0	0
RNO	OAK	69	7	0
RNO	SFO	104	42	255
ROC	BOS	215	3	13
ROC	EWR	135	19	0
ROC	HPN	117	0	0
ROC	LGA	116	0	0
ROC	ORD	366	3	22
SAN	ORD	1440	15	89
SAN	PHX	192	0	0
SAN	SFO	288	0	8
SAT	DFW	125	3	39
SAT	ELP	348	5	27
SAT	LAX	943	6	12
SAV	ATL	101	3	22
SDF	ATL	203	12	117
SDF	DCA	321	12	24
SDF	DTW	189	11	59
SDF	LGA	508	24	72
SDF	MDW	147	-9	-29
SDF	MEM	206	17	88
SDF	ORD	144	-12	-53
SDF	PIT	239	0	0
SDF	STL	136	2	10
SEA	DEN	808	6	48
SEA	LAX	765	0	0
SEA	MSF	1134	8	32
SEA	ORD	1404	4	52
SEA	SFO	507	19	385
SFO	ABQ	698	6	17
SFO	ATL	1776	25	129
SFO	BOS	2275	29	115
SFO	BUR	182	3	30
SFO	DFW	1207	12	128
SFO	DEN	726	-2	-35
SFO	EWR	2326	26	105
SFO	GEG	545	4	12

AIRPORT PAIR FROM	AIRPORT PAIR TO	VOR ROUTE MILES	ROUTE MILES VOR -RNAV	FLIGHT MILES VOR -RNAV
SFO	IAD	2010	7	38
SFO	JFK	2129	26	516
SFO	LAS	278	29	356
SFO	LAX	182	3	163
SFO	MDW	1498	16	0
SFO	MKC	1159	4	8
SFO	MSP	1285	7	49
SFO	ONT	187	2	22
SFO	ORD	1498	16	484
SFO	PDX	380	1	14
SFO	PHX	490	32	164
SFO	SEA	492	3	65
SFO	SLC	425	9	49
SFO	SNA	182	-1	-14
SFO	STL	1409	5	11
SHV	JAN	102	1	8
SJC	BUR	180	0	-2
SJC	LAX	180	1	17
SJC	ONT	185	1	5
SJC	SNA	180	-4	-32
SLC	BOI	164	-2	-10
SLC	DEN	245	0	9
SLC	LAS	243	9	86
SLC	LAX	432	0	0
SLC	ORD	991	5	42
SLC	PDX	466	5	15
SLC	SFO	425	13	82
SMF	LAX	239	2	55
SMF	ONT	243	6	0
SNA	SFO	198	12	114
SNA	SJC	192	6	48
STL	ATL	334	1	7
STL	BAL	569	43	43
STL	CLE	358	20	140
STL	DFW	399	1	10
STL	DAY	216	4	23
STL	DCA	532	4	31
STL	DEN	599	0	-6
STL	DTW	320	27	139
STL	IND	122	9	119
STL	JFK	703	13	41
STL	LAX	1273	7	53
STL	LGA	692	2	20
STL	MDW	120	-2	-26
STL	MEM	132	-1	-22
STL	MKC	118	0	4
STL	MKE	191	-5	-17
STL	ORD	120	-2	-79

AIRPORT PAIR FROM	AIRPORT PAIR TO	VOR ROUTE MILES	ROUTE MILES VOR -RNAV	FLIGHT MILES VOR -RNAV
STL	PHL	629	3	15
STL	PHX	1010	2	12
STL	PIT	407	8	24
STL	SDF	136	3	15
STL	SFO	1440	14	28
STL	TUL	217	0	-4
SYR	DTW	241	3	15
SYR	ORD	432	3	9
TEB	CLE	266	6	0
TPA	ATL	301	35	570
TPA	CLE	728	5	5
TPA	DTW	797	7	27
TPA	EWR	816	6	19
TPA	FLL	103	18	128
TPA	JFK	928	8	0
TPA	MIA	103	18	329
TPA	MSY	353	0	0
TPA	ORD	793	6	38
TUL	DFW	122	0	1
TUL	MKC	110	5	29
TUL	ORD	418	10	32
TUL	STL	218	2	15
TUS	ELP	149	5	47
TUS	LAX	285	0	0
TUS	ORD	1378	11	54
TYS	DCA	294	14	87

3.3 ENROUTE LOW ALTITUDE RNAV BENEFITS

The analysis described in Section 3.1 and 3.2 focused on quantifying those benefits resulting from the use of RNAV in the high altitude (at or above FL 180) enroute environment. This companion analysis, examining the low altitude regime, was undertaken to provide an assessment of the potential RNAV benefits that could be obtained by general aviation owners and operators, commuter carriers, air taxi operators and other user groups who normally operate below 18,000 feet.

The high altitude studies made use of a comprehensive 429 airport pair RNAV route structure, developed by NAFEC,to directly identify RNAV route lengths for subsequent comparison with corresponding VOR routes. However, a comparable low altitude RNAV structure had not been designed prior to initiation of this task, and the design of such a structure on a national scale was beyond the scope of this effort. An approach was developed whereby a low altitude route structure was developed for a limited geographical area, the route length benefits determined, and the results extrapolated to a national result based on common airport pair characteristics. This approach is summarized in the flow diagram of Figure 3.11 and described in detail in the following sections.

3.3.1 Sample Area Selection for Low Altitude RNAV Route Design

The selection of a specific geographic region, was established as a ground rule to ensure that the routes of the resulting low altitude RNAV structure would have realistic interactions not only with the surrounding VOR routes, but with other RNAV routes as well.

The method ultimately adopted for this analysis was to select a geographical area based on its diverse characteristics which, if possible, should reflect all conditions found on a national scale, but not necessarily in the same proportion. In this case, the individual airport pair payoffs were to be related to certain characteristics prevalent in the airport pair by means of a regression analysis.

The resulting regression equation was then used in combination with the appropriate characteristics developed for each airport pair having a low altitude IFR exchange [23] to predict individual airport pair payoffs. Those results were then aggregated to produce a national low altitude payoff.

Data from the IFR Peak Day Tape, supplemented by airport location information obtained from FAA airport directory tapes was used to establish the distribution of low altitude operations among the states. To facilitate the analysis, nine states and the District of Columbia were merged into three "Larger States", where (A) relatively light traffic existed over several small adjacent states, (B) traffic was concentrated in a "metropolitan" area encompassing parts of two states, and (C) several adjacent states encompassed a relatively small geographical area. This resulted in a total of 42 states including the following merged states:

APPROACH TO DETERMINE RNAV LOW ALTITUDE ROUTE LENGTH BENEFITS

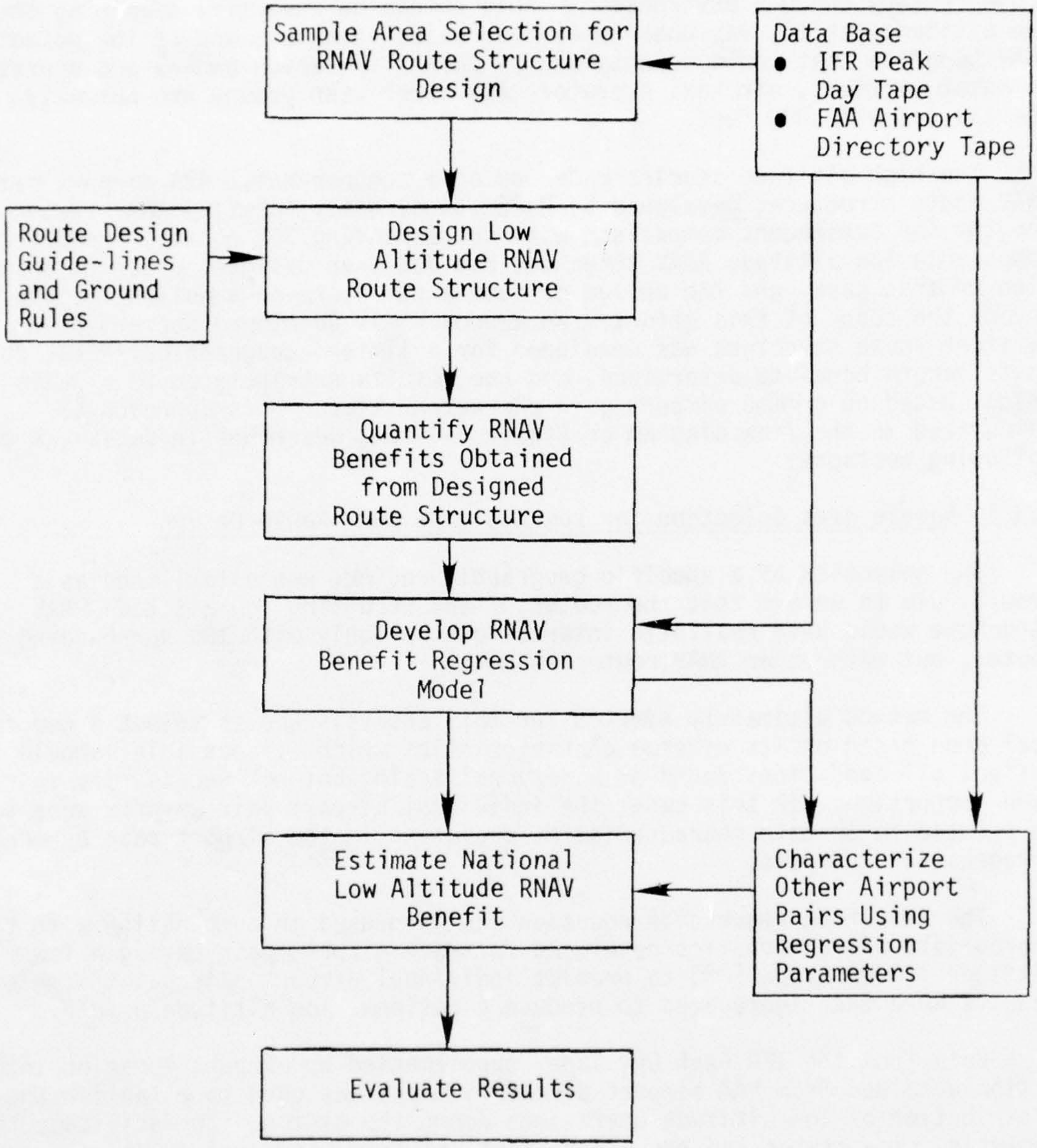


Figure 3.11 Approach to Determine RNAV Low Altitude Route Length Benefits

"MERGED STATE"	CONSISTS OF
(A)	Connecticut, New Hampshire, Vermont, Rhode Island, and Massachusetts
(B)	New York and New Jersey
(C)	Delaware, District of Columbia and Maryland

The IFR tape processing produced a total of 20950 low altitude flights, encompassing 8076 airport pairs and 1985 airports. The airport directory provided the locations (latitude, longitude and state) for 1336 of these airports. The discrepancy between the number of airports contained on each data source can be attributed primarily to the fact that the IFR tape includes Alaska and Hawaii flights, as well as departures to foreign airports. The airport directory does not contain foreign airports, and Alaska and Hawaii airports were not processed since only those states within the contiguous United States were included in this analysis.

The basic state and state pair results are summarized in Table 3.19. It can be seen that the State of California has by far the greatest intra-state traffic exchange with Texas ranked number two.

Table 3.19 Low Altitude Intra-State Traffic
(Top Twenty)

States	Peak Day Exchange
1. California	1272
2. Texas	751
3. New York/New Jersey	668
4. Florida	502
5. Ohio	439
6. Conn/VT/NH/RI/Mass	415
7. Michigan	401
8. Illinois	369
9. Pennsylvania	355
10. N. Carolina	224
11. Georgia	210
12. Missouri	192
13. Tennesse	181
14. Kansas	181
15. Wisconsin	172
16. Colorado	170
17. Delaware/DC/MD	159
18. Iowa	149
19. Louisiana	140
20. Washington	131

Since the average hop length of general aviation flights is only 160 miles and low altitude traffic is dominated by general aviation, it was felt that a large state with a large amount of intra-state traffic would be the most appropriate for analysis of a low altitude RNAV route structure, and thus California was chosen. California contains two high density terminal areas (SFO, LAX), several of medium density, and an abundance of low density airports. In general, the large number of airport pairs (275) and flights (1272) should insure the maximum possible diversity among route characteristics.

3.3.2 California Low Altitude RNAV Route Design

The primary objective of the route design effort was to establish the low altitude enroute length benefit data for a specific area, which would subsequently serve as a baseline for extrapolation. The terminal area effects were, therefore, not addressed. For the small terminals, the terminal area was defined simply as a radius of 5 nm which approximated the control zone, airport traffic area, or airport advisory area. Routes passing over these terminal areas were assumed to be unaffected by the terminal. In the two high density terminal areas, encompassing Los Angeles and San Francisco regions, respectively, the RNAV routes were designed so that they began and/or ended at current VOR compulsory reporting points. Although the RNAV arrival and departure waypoints may be expected to be in slightly different locations in an RNAV environment, the impact of these new locations on the aggregate results of this analysis would be negligible.

The RNAV structure was permitted to overlay the existing VOR airway segments if appropriate and necessary to produce an efficient RNAV structure. Thus, the resulting RNAV route structure is the composite of a portion of the VOR structure plus unique RNAV route segments. As a result the RNAV routes were not adversely impacted by the remaining VOR structure. It was generally found, as expected, that whenever the VOR routes were inordinately long, and therefore, inferior to the RNAV routes, they tended to deviate sufficiently from the great circle arc so as not to interfere with the resulting optimal RNAV design.

Intersecting segments, both within the RNAV structure and between RNAV and VOR routes, were designed in a manner so as to maximize the intersection angles. The 15° nominal minimum intersection angle, used as a guideline for high altitude RNAV design produced by NAFEC, was also applied to this study. However, as in the high altitude designs, a few exceptions are necessary. The primary cause of small intersection angles in the California low altitude design stems from the RNAV/VOR merging or demerging at VOR stations. In many instances, the number of VOR routes intersecting at a VOR station was such that no space existed for the design of an additional route with a 15° separation. When there was no reasonable alternative, the 15° requirement was relaxed. The primary intent of the intersection angle requirement was to facilitate the separation of routes. Larger angles result in less common airspace. Routes which are intended to be procedurally separated (i.e., by their route width) would be separated over a longer distance when larger

intersection angles are used. For this reason, however, the 15° requirement was not found to be as appropriate in the low altitude airspace as at the higher altitudes.

The number of intersections in combination with the small average route segment lengths and the lack of predominant directions of flow virtually prohibit the procedural separation of segments. In several areas of California, the current low altitude VOR structure is already so complex that procedural separation is rarely evident. In general, segments which are at all close to one another intersect. While certain RNAV segments were designed intentionally to achieve separation (based on a $\pm$ 4 nm route width), the primary and most restrictive constraint was the overall structure complexity.

The final ground rule applicable in the route design effort was that airport pairs with a great circle distance of less than 50 nm were not considered. The rationale for this decision was based on two factors. First, short flights where either of the airports were within a major terminal area would produce only a minimal amount of enroute travel. If both terminals are in high density areas, as is frequently the case along the east coast, travel outside the terminal area could be completely eliminated. Although subjective, this was the rationale for the choice of 50 nm as the specific exclusion criteria. The second reason for excluding these airport pairs was that the peculiarities of the terminals themselves can cause a considerable variation in the conventional (VOR) route lengths. If both of the terminals have VORs a "direct" route is available. The actual flight length, however, may be considerably longer due to the VOR/terminal orientation. These route length variations occur on longer flights as well, but their relative impact on the total route length is reduced. It was known that these route length variations could not be adequately accounted for in the regression analysis, and their inclusion would, therefore, not be advantageous. Of the original 275 California airport pairs listed on the peak day tape [23], 197 had distances of 50 nm or more.

VORTAC coverage and altitude restrictions were also considered in producing the RNAV design. However, it was considered important not to influence the California design or its routes length results by coverage or terrain phenomena peculiar to California. As a rule, the VOR routes tended to fly directly over mountainous areas, being constrained only by minimum altitude requirements. In these areas, the RNAV routes were similarly designed, assuming that comparable minimum altitude requirements would be imposed.

Of greater concern were the cases where the VOR routes circumvented specific geographic areas. In these instances, determination of the cause of the deviation was necessary. If the VOR's were not suitably located, this was assumed to be the sole cause of the route bending. Since complete coverage data was not available, an estimate was made as to whether or not adequate RNAV (VORTAC) coverage existed. If coverage was reasonably certain, an RNAV route was designed. If coverage was unlikely, a conservative approach was taken and the RNAV route was redesigned to utilize known coverage. If coverage was not known, the airport pair was eliminated from the analysis. Airport pairs were also eliminated when the cause of the VOR deviation could not be ascertained.

If coverage and terrain factors indicated that a VOR route shorter than the charted VOR route could be established, the RNAV route was considered to have an unfair advantage. On the other hand, setting the RNAV benefit equal to zero would unfairly reduce the overall RNAV payoff averaged over all routes. This occurred in a number of instances, due to the fact that a large number of airport pairs considered included a great many of very low traffic exchange. In all, 17 airport pairs were discarded on these grounds, leaving the 180 which were subsequently used in this analysis.

The route design procedure consisted of sequentially analyzing each airport pair and adding RNAV-peculiar segments as appropriate. The aggregate structure become more complete as the process evolved. As each airport pair was analyzed, the first consideration was whether or not the current composite structure (i.e., the existing VOR structure plus any newly added RNAV segments) provided a route which did not significantly deviate from the direct path. If this was the case, no additional RNAV segments were deemed necessary. However, when an acceptable route did not exist, RNAV segments were added where feasible, either so as to build the entire route or to cut corners on an existing route.

In certain instances, a previously designed RNAV segment would be found to be detrimental to the design of another airport pair. In these instances, the airport pair exchange and the relative value of each segment was evaluated in order to arrive at a reasonable compromise which would potentially provide the greatest RNAV payoff for the most traffic.

The sequential nature of this procedure was such that the results improved with subsequent iterations. Routes which did not appear to justify additional RNAV segments were able to take advantage of additional segments which were added for other airport pairs. The entire process was repeated several times until additional changes did not appear to produce a more efficient design. In all, 108 of the 180 California airport pairs retained as candidates for RNAV routes were able to benefit from the design of RNAV segments.

The resultant RNAV structure is depicted in Figure 3.12. The dotted lines represent exclusive RNAV route segments. The heavy solid lines are existing VOR routes, which are also proposed as RNAV route segments to supplement the unique RNAV segments, in order to provide a complete RNAV structure serving each of the 180 airport pairs.

The route length computations were based on determining the shortest RNAV and VOR routes which were made available in each of the structures. All routes within the terminal areas were assumed to be great circle arcs from the point of intersection with the terminal area boundary (or reporting point) to the airfield. Table 3.20 presents the final California route length results for each airport pair. The average RNAV benefit relative to VOR is 2.92% on a route mile basis and 2.61% on a flight mile (traffic weighted) basis. The total VOR enroute route length, used only as the denominator in the RNAV percent benefit computation, was obtained by assuming individual enroute route lengths equal to the airport-to-airport lengths minus 10 nm (5 miles at each end).

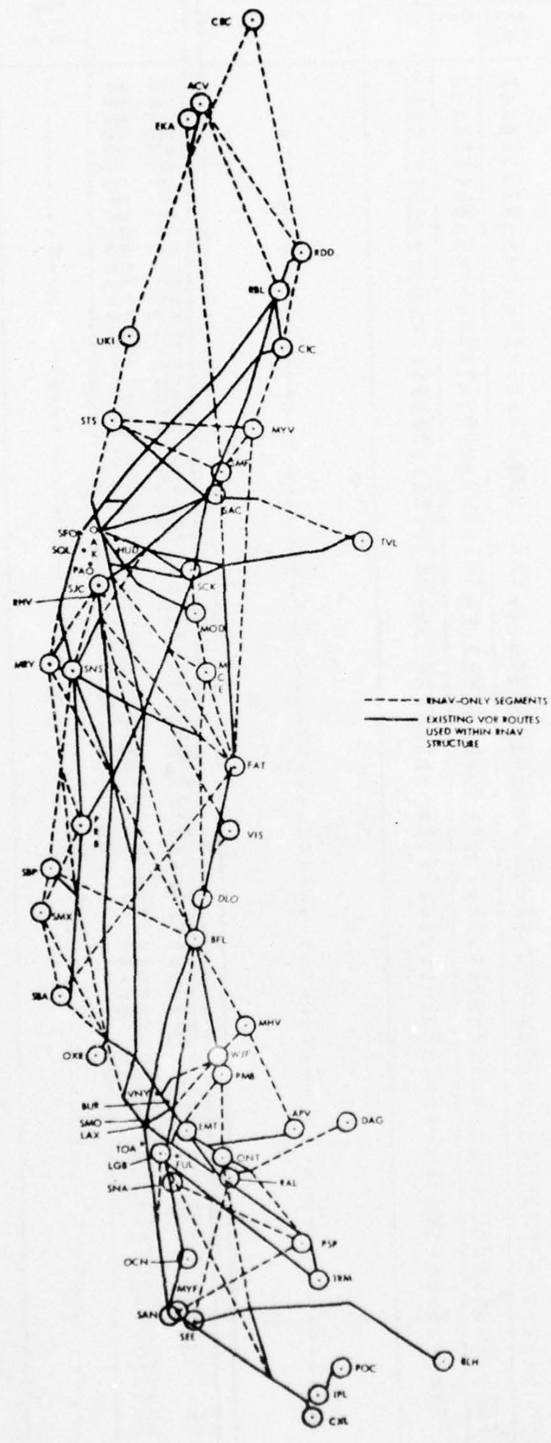


Figure 3.12 California Low Altitude RNAV Route Structure

Table 3.20

California Low Altitude RNAV Route Structure Results

AIRPORT PAIR		NO. OF FLTS. PEAK DAY (REF. 1)	AIRPORT TO AIRPORT ROUTE LENGTH (NM)			RNAV ROUTE LENGTH BENEFIT (NM)
			GREAT CIRCLE	RNAV	VOR	
ACV	OAK	1	214	216	227	11
ACV	RBL	2	98	78	105	7
ACV	RDD	2	86	88	105	17
ACV	SAC	1	190	192	205	13
ACV	SFO	7	217	218	229	11
ACV	SMF	2	179	180	193	13
ACV	STS	1	159	160	165	5
ACV	UKI	2	118	118	126	8
APV	BFL	2	105	105	113	8
APV	SNA	1	63	70	70	0
BFL	BUR	4	81	81	83	2
BFL	FAT	54	87	87	87	0
BFL	LAX	21	94	95	95	0
BFL	LGB	3	106	106	108	2
BFL	MCE	1	132	133	134	1
BFL	MRY	1	152	153	161	8
BFL	OAK	2	205	208	214	6
BFL	PMD	1	67	68	68	0
BFL	RDD	1	341	342	349	7
BFL	SAN	2	186	188	188	0
BFL	SBP	1	78	78	87	9
BFL	SCK	1	181	182	188	6
BFL	SFO	2	207	209	215	6
BFL	VIS	1	55	58	58	0
BLH	PSP	4	90	93	93	0
BLH	SAN	2	135	148	148	0
BUR	IPL	2	161	179	183	4
BUR	MCE	1	213	214	216	2
BUR	MHV	1	53	55	57	2
BUR	MYF	2	102	111	111	0
BUR	OAK	2	282	282	282	0
BUR	PAO	1	268	271	271	0
BUR	PSP	3	94	96	96	0
BUR	SAN	18	105	106	108	2
BUR	SBA	1	74	74	76	2
BUR	SBP	1	129	134	137	3
BUR	SFO	1	283	287	287	0
BUR	SJC	4	257	260	260	0
BUR	SMX	3	111	113	122	9
BUR	TVL	1	292	292	292	0
CEC	CIC	1	161	163	192	29
CEC	SFO	2	264	264	279	15
CIC	OAK	1	125	126	126	0
CIC	SAC	1	78	79	81	2
CIC	SFO	4	133	137	137	0
CIC	SMF	1	67	68	69	1
CXL	SFO	1	448	457	467	10
DAG	RAL	2	63	64	75	11
DLO	VNY	1	100	102	102	0
EKA	UKI	1	109	112	123	11
EMT	SAN	2	91	94	94	0
FAT	LAX	2	181	182	182	0
FAT	LGB	2	193	193	194	1
FAT	MOD	4	78	79	89	10
FAT	MRY	2	103	105	108	3
FAT	OAK	9	132	134	148	14
FAT	SAC	4	134	134	134	0
FAT	SBA	1	141	142	156	14
FAT	SCK	5	98	99	108	9
FAT	SFO	17	136	137	151	14
FAT	SJC	11	111	114	123	9
FAT	SMF	4	145	145	148	3
FAT	SNS	1	91	93	96	3
FUL	MYP	1	76	87	87	0
FUL	SAN	1	79	86	86	0
FUL	SBA	1	98	101	114	13
FUL	SNS	1	244	253	257	4
FUL	VIS	1	162	164	166	2
HWD	MRY	2	65	65	71	6
HWD	RBL	1	150	152	152	0
HWD	WJF	1	257	259	265	6
IPL	LAX	2	156	167	172	5
IPL	ONT	1	125	138	144	6
IPL	SAN	16	81	87	87	0
IPL	SMA	1	125	134	141	7
LAX	MHV	1	68	69	71	2
LAX	MRY	1	231	234	247	13
LAX	OCN	1	68	71	71	0
LAX	PSP	14	94	96	96	0
LAX	SAN	113	94	94	94	0
LAX	SBA	29	76	78	82	4
LAX	SFO	7	292	295	297	2
LAX	SJC	1	267	268	270	2
LAX	SMF	1	324	324	327	3
LAX	SMX	15	116	117	123	6
LAX	TRM	2	113	118	118	0
LGB	MRY	1	245	250	263	13
LGB	OAK	2	306	310	312	2
LGB	PSP	1	82	83	83	0
LGB	SAN	14	81	81	84	3
LGB	SBA	1	91	94	98	4
LGB	TRM	5	99	99	99	0
MOD	RDD	1	183	191	191	0
MOD	SFO	3	67	68	68	0
MOD	SMF	1	70	73	73	0
MOD	VNY	1	237	241	247	6
MRY	OAK	6	70	71	77	6
MRY	PRB	1	80	81	88	7
MRY	SAC	2	117	118	124	6
MRY	SBA	1	162	164	167	3
MRY	SFO	26	66	66	68	2
MRY	SMX	2	121	123	125	2
MRY	VNY	1	217	224	235	11
MYP	POC	1	83	104	110	6
MYP	SNA	1	63	67	67	0
MYV	RDD	1	91	91	94	3
MYV	STS	2	68	68	74	6
OAK	PRB	2	144	145	146	1
OAK	RDD	2	167	170	170	0
OAK	SAC	4	58	58	58	0
OAK	SMF	5	65	69	69	0
OAK	SNS	4	69	70	71	1
OAK	STS	3	55	56	63	7
OAK	TOA	1	301	305	305	0
OAK	TVL	3	126	130	130	0
OAK	VNY	1	277	280	280	0
ONT	PSP	4	56	59	62	3
ONT	SBA	2	112	113	115	2
ONT	SFO	1	315	317	326	9
ONT	SNS	1	250	254	260	6
ONT	WJF	3	51	52	56	4
OXR	SCK	1	242	248	250	2
PAO	SNS	1	53	55	56	1
PRB	SFO	4	143	146	146	0
PRB	SJC	2	119	120	122	2
PSP	SAN	2	73	74	86	12
PSP	SMO	4	97	102	102	0
PSP	SNA	2	68	68	73	5
RAL	SJC	1	299	300	310	10
RAL	TRM	1	66	70	70	0
RBL	SJC	1	168	175	175	0
RBL	SMF	1	92	92	92	0
RDD	SAC	2	125	126	126	0
RDD	SFO	10	173	175	175	0
RDD	SMF	3	113	114	114	0
RHV	SAC	1	72	73	73	0
RHV	STS	1	84	87	94	7
SAC	SFO	2	68	68	68	0
SAC	SJC	4	71	72	72	0
SAC	SNS	3	111	111	117	6
SAC	SQL	1	69	71	71	0
SAC	STS	1	61	63	63	0
SAC	TVL	2	73	76	87	11
SAN	SMF	1	417	419	422	3
SAN	SMO	1	99	99	99	0
SAN	SNA	8	65	67	67	0
SAN	TOA	1	86	86	86	0
SAN	VNY	3	109	110	110	0
SBA	SBP	1	62	62	76	14
SBA	SFO	1	227	233	233	0
SBA	SMO	2	72	75	79	4
SBA	TOA	1	83	87	91	4
SBA	VNY	1	68	69	71	2
SBP	SFO	1	165	168	178	10
SBP	SNS	1	97	98	112	14
SCK	SFO	14	56	63	63	0
SCK	SMF	2	50	51	51	0
SCK	SQL	2	53	55	55	0
SCK	TVL	2	83	84	84	0
SCK	VNY	1	258	263	270	7
SFO	SMF	49	74	78	78	0
SFO	SMX	1	187	189	201	12
SFO	SNS	6	67	70	70	0
SFO	STS	17	57	58	65	7
SFO	TOA	1	301	306	306	0
SFO	TVL	5	135	140	140	0
SFO	UKI	2	98	98	107	9
SFO	VIS	1	162	167	175	8
SFO	VNY	1	278	281	281	0
SJC	SMF	9	81	83	83	0
SJC	SMO	2	262	266	266	0
SJC	SMX	3	164	165	174	9
SJC	TVL	3	129	133	133	0
SMF	SMO	1	319	319	322	3
SMF	SMX	1	234	235	240	[illegible]
SMF	STS	4	58	59	67	8
SMX	SNS	1	120	121	128	7
SQL	STS	1	65	65	72	7
STS	VNY	1	332	337	344	7
TRM	VNY	1	120	124	124	[illegible]

3.3.3 Regression Model Development

The RNAV low altitude route length benefit potential within the State of California, identified in Section 3.3.2, was used as a basis for extrapolation to a national scale. This was accomplished by applying a regression analysis to the California data base in order to develop an analytical expression for use in estimating low altitude RNAV route length benefits as a function of specific airport pair characteristics.

The capability to extrapolate the regression analysis results to include the thousands of airport pairs for which route designs were not made is the key element which governed the methods used in the regression analysis itself. If the sole task of the regression analysis was to characterize the California benefits, an accurate and feasible approach would include quantitative consideration of the terrain features, VORTAC locations, their orientations relative to the terminals and perhaps even the interaction between the high and low altitude route structures. The computation of these characteristics for each of the 8,000 national airport pairs, however, was beyond the scope of this endeavor. Therefore, to facilitate automation and computational efficiency, the potential regression variables were confined to the data obtained from the initial IFR Tape and Airport Directory tape processing.

Thus, the first step in this regression analysis was to extract from the data base as many potential independent variables as possible which may have a bearing on the RNAV benefits. The following characteristics (independent variables) were computed for each of the 180 airport pairs in the California design:

- the number of departures from each airport; (2 characteristics)
- the number of airports and their total departures within 25 nm of each of the arrival and departure airports; (4 characteristics)
- the number of airports and their departures in the region connecting the two 25 nm radius terminal area circles (swath width of 50 nm); (2 characteristics)
- the number of airport pairs and their total flights whose great circle arcs intersect that of the airport pair being considered; (2 characteristics)
- the airport pair exchange; and
- the great circle distance.

The first item above is a measure of the activity at the specific airport. The second item relates to the general traffic density within each terminal area. The 25 nm value was used, as this generally coincides with the location of low altitude arrival and departure waypoints at the larger terminals. This is the average radius for low altitude arrival waypoints based upon recent RNAV terminal design studies [2]. Logically, smaller terminals do not exert influence over this great a distance. However, by including the number of departures of these terminals, the regression model is provided the necessary information to distinguish the larger terminals from the smaller (assuming that the distinction improves the model). The same comments also apply to item 3, the airports overflown. The characteristics in item 4 are indicative

of the general design complexity of the area. The number of flights is potentially indicative of the suitability of the existing VOR route.

The characteristics listed above, in combination with the route length results of the design effort, were the fundamental data base used in this regression analysis. It is apparent that there are a great many potential regression models which can be derived from these data. In order to converge upon a satisfactory model in an expeditious and cost-effective manner, the regression attempts were designed to achieve the following:

(1) Determine the most suitable dependent variable and the independent variable which contributes most significantly to the regression fit.

(2) Determine the improvement in the regression fit of nonlinear variations of the significant variables.

(3) Compare the resulting models and select that which is the most appropriate.

A detailed description of the regression attempts and the selection of the regression model is given in Appendix D.

3.3.4 Extrapolation to a National Scale

The expression relating the RNAV absolute mileage benefit to (1) the great circle distance, (2) number of airports within each terminal area, and (3) number of airports overflown (using a swath width of ± 25 nm about the great circle ground track) was used to estimate the RNAV benefit for each airport pair whose great circle distance was greater than 50 nm and which had at least one low altitude exchange listed on the Peak Day Tape. This procedure required the computation of each of the four aforementioned regression variables for each airport pair analyzed, insertion into the regression equation and the computation and aggregation of the resulting benefits.

The only instances when the regression equation was altered were when negative RNAV benefits resulted. This may occur, according to the regression model, on short flights in very high density areas. Within the ground rules of the route design effort, however, negative RNAV benefits cannot occur (the option to duplicate VOR routes always exists) and a zero RNAV benefit was assumed under these circumstances.

The absolute RNAV benefit results provided the necessary data to estimate the per route, per flight and total route and flight mile savings. In order to express these results in terms of RNAV percent savings relative to VOR, it was necessary to estimate the specific VOR route lengths, which were not directly available from the extrapolation. Since the percent savings are derived by dividing a small mileage saving by a large route length, the sensitivity of the results to this estimation process is

negligible, and a sophisticated procedure was not required. Instead, the relationship of RNAV to great circle route length in the California structure was assumed to be representative of that relationship in the entire U.S. structure. The VOR route lengths could then be estimated by adding the difference in RNAV and great circle distance plus the difference in VOR and RNAV distance to the great circle distance. Within California, the average RNAV route was 1.89% longer than the great circle distance. Thus, for each airport pair over which the extrapolation was made, the RNAV route length of that pair was assumed to be the great circle distance plus 1.89%. The VOR route length was therefore derived by adding to the RNAV route length the estimated RNAV benefit over VOR. For the percent computations, 10 nm (5 nm in each terminal area) was subtracted from each route to account for the terminal areas.

Tables 3.21 through 3.23 present the national, inter-state benefit, and intra-state summaries, respectively. The regression equation coefficients are described in Appendix D. Of primary importance is the 2.3% per route RNAV benefit. The estimates were derived from consideration of individual airport pairs, with negative RNAV benefits replaced with zero. For this reason, the average benefits shown in the tables cannot be derived by analysis of the average parameter values.

Of particular interest is the variance between the inter-state and intra-state results. The estimated percent benefit of intra-state RNAV traffic is roughly twice that of inter-state traffic. This phenomenon can be attributed to several factors, not all of which necessarily pertain to inherent RNAV capabilities. It can be seen that the average terminal area density for inter-state traffic is somewhat higher than for intra-state. The number of airports overflown is approximately four times that of the intra-state results; more importantly, twice as many airports are overflown per flight length. One would expect that the longer flights would tend to interconnect areas of higher than average polulation density. A reduced RNAV benefit is therefore not so much the result of RNAV inefficiency, but more probably the result of a more comprehensive VOR structure which would be expected in such areas. The complexity of the VOR structure and its consequent interference with the RNAV routes may also be a factor. Further, the inter-state results tend to be consistent with the intra-state results for these regions of the country.

Figure 3.13 presents the average RNAV per route/per flight benefits % for each state based upon the intra-state results. The California route mile results are the same as those obtained in the route design effort. This is a necessary consequence of the regression analysis, although a slight discrepancy arises from the fact that the results presented here include the 17 airport pairs which were not considered in the design. The flight mile percent benefit, however, exhibits estimation error (3.0% compared to 2.6%), attributed to the inability of the regression model to provide a perfect fit.

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The results of this study indicate that higher RNAV benefits are provided in low density areas and vice-versa. The average flight length, however, also had a marked impact on the percent results. Delaware/Maryland/DC, for example, wherein the flights are necessarily short, actually received a very small absolute benefit (2 nm per route). The average great circle distance of only 79 nm caused the percent benefit to be unexpectedly high (relative to the subject state).

Table 3.24 summarizes the intra-state benefit derivation for the average per route savings (see Appendix D for regression parameters). The extent to which each characteristic is affected is shown. The states are listed in order of their absolute benefit. The most pronounced trend is found in the benefit degradation due to the smaller terminal area. This indicates that RNAV can produce a substantial benefit when only one of the terminals is in a high density area but this benefit is reduced considerably when both are high density. The apparent inability of RNAV to provide an enroute benefit for airport pairs where both terminals are of high density can be attributed to the fact that a good portion of these routes are contained within the terminal areas and generally good VOR routes already exist between these areas.

Based on this extrapolation, it was estimated that the average per flight mile benefit of RNAV over VOR in the low altitude structure is 2.36% (Table 3.21).

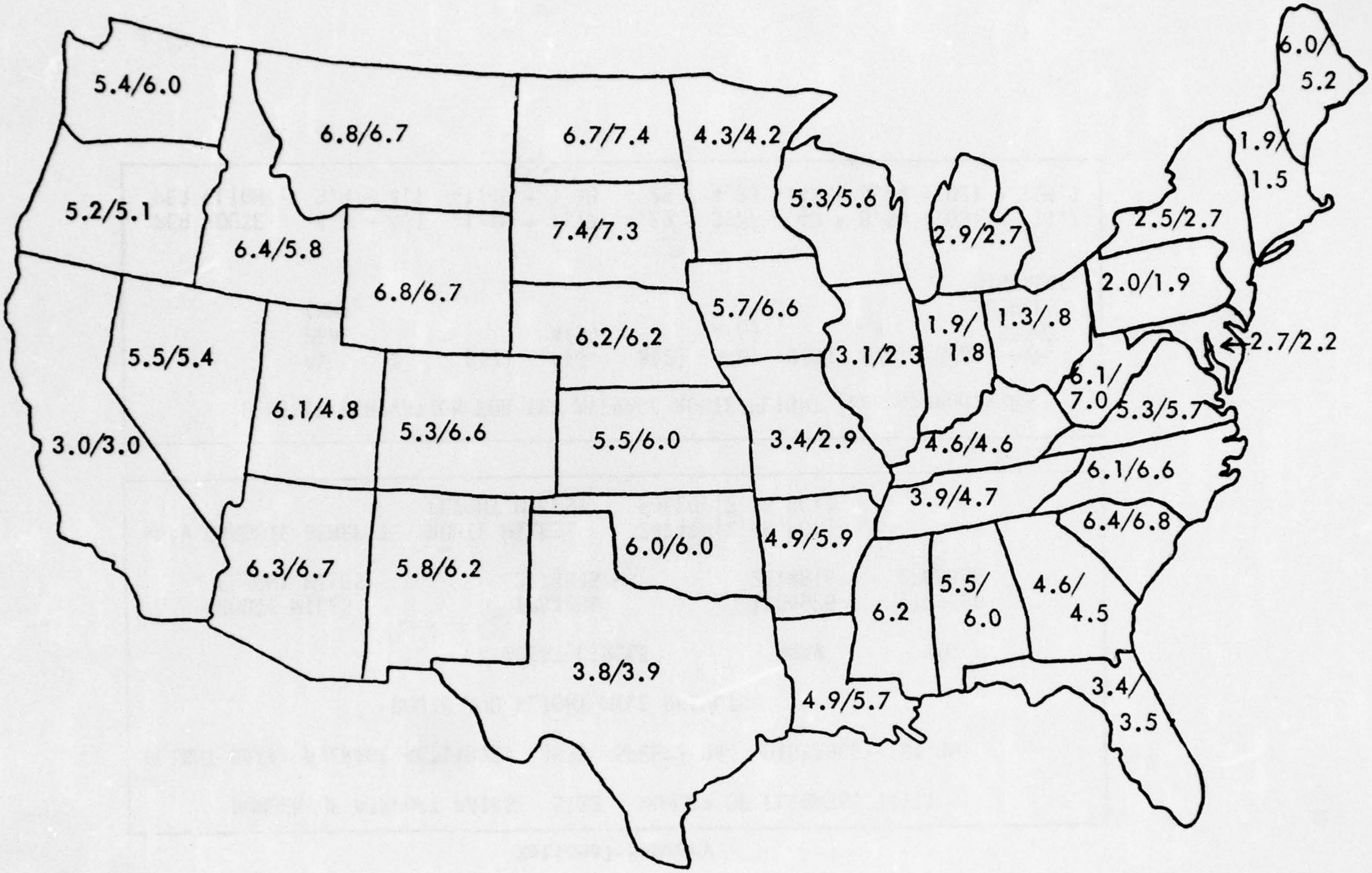


Figure 3.13 RNAV Route Mile/Flight Mile Percent Benefit Relative to VOR Routes Low Altitude Intra-State Routes

Table 3.21

National Summary

NUMBER OF AIRPORT PAIRS: 5122 NUMBER OF FLIGHTS: 14111

FLIGHT DATA: AVERAGE ALTITUDE: 8539 SPEED: 244 DISTANCE: 154 NM

ROUTE AND FLIGHT MILE RESULTS

	GREAT CIRCLE	RNAV	VOR
ROUTE MILES	1084486	1104926	1129666
FLIGHT MILES	2173845	2214816	2268436

RNAV ENROUTE BENEFIT: ROUTE MILES: 24741 (2.19 PCT)
FLIGHT MILES: 53620 (2.36 PCT)

BENEFIT DERIVATION FOR THE AVERAGE ROUTE/FLIGHT (See Appendix A)

	AVG. BEN. (NM)		C	B(1)		AVG. A(S)	B(2)		AVG. A(L)	B(3)		AVG. θ	B(4)		AVG. GREAT CIRCLE DISTANCE
PER ROUTE:	4.8	=	4.1	-1.45	*	1.17	-.29	*	3.77	-.43	*	8.56	+.031	*	211.7
PER FLIGHT:	3.8	=	4.1	-1.45	*	1.38	-.29	*	4.23	-.43	*	6.24	+.031	*	154.1

Table 3.22

Inter-State Summary

NUMBER OF AIRPORTS PAIRS: 3336   NUMBER OF FLIGHTS: 7855

FLIGHT DATA: AVERAGE ALTITUDE: 9172 SPEED: 247 DISTANCE: 191 NM

ROUTE AND FLIGHT MILE RESULTS

	GREAT CIRCLE	RNAV	VOR
ROUTE MILES	864084	880374	897123
FLIGHT MILES	1497315	1525542	1554310

RNAV ENROUTE BENEFIT: ROUTE MILES: 16749 (1.87 PCT)
FLIGHT MILES: 28767 (1.85 PCT)

BENEFIT DERIVATION FOR THE AVERAGE ROUTE/FLIGHT (See Appendix A)

	AVG. BEN. (NM)		C	B(1)	AVG. A (S)	B(2)	AVG. A (L)	B(3)	AVG. θ	B(4)	AVG. GREAT CIRCLE DISTANCE
PER ROUTE:	5.0	=	4.1	-1.45 *	1.33	-.29 *	4.02	-.43 *	11.38	+.031 *	259.0
PER FLIGHT:	3.7	=	4.1	-1.45 *	1.70	-.29 *	4.70	-.43 *	9.02	+.031 *	190.6

Table 3.23

Intra-State Summary

NUMBER OF AIRPORT PAIRS: 1786 NUMBER OF FLIGHTS: 6256

FLIGHT DATA: AVERAGE ALTITUDE: 7745 SPEED: 240 DISTANCE: 108 NM

ROUTE AND FLIGHT MILE RESULTS

	GREAT CIRCLE	RNAV	VOR
ROUTE MILES:	220402	224558	232550
FLIGHT MILES:	676530	689287	714140

RNAV ENROUTE BENEFIT: ROUTE MILES: 7992 (3.44 PCT)
FLIGHT MILES: 24853 (3.48 PCT)

BENEFIT DERIVATION FOR THE AVERAGE ROUTE/FLIGHT

	AVG. BEN. (NM)		C	B(1)	AVG. A(S)	B(2)	AVG. A(L)	B(3)	AVG. θ	B(4)	AVG. GREAT CIRCLE DISTANCE
PER ROUTE:	4.5	=	4.1	-1.45 *	.87	-.29 *	3.30	-.43 *	3.28	+.031 *	123.4
PER FLIGHT:	4.0	=	4.1	-1.45 *	.98	-.29 *	3.63	-.43 *	2.76	+.031 *	108.1

Table 3.24

Average Intra-State RNAV Induced Per Route Benefit for Each State (Peak Day Traffic)

State	No. of Airport Pairs	No. of Flts.	Average Great Circle Dist.	RNAV Benefit Components (Appendix D): Constant	Smlr. Terminal Area	Lrgr. Terminal Area	Overflown Airport	Route Length (3% of Great Circle	Corr. to Acc. for Zero Benefit Routes	RNAV Absolute Benefit (nmi)	% Savings Relative for VOR
NEV	6	15	158	4.06	.00	.00	-.21	4.96	.00	8.80	5.51
NM	7	11	143	4.06	.00	.00	-.12	4.49	.00	8.43	5.85
ID	7	25	117	4.06	.00	-.04	-.24	3.69	.00	7.46	6.37
WYO	9	25	111	4.06	.00	-.10	.00	3.47	.00	7.44	6.75
NDA	13	56	112	4.06	.00	.00	-.13	3.50	.00	7.43	6.69
MON	25	67	109	4.06	.00	.00	-.14	3.44	.00	7.36	6.76
ARI	7	39	118	4.06	-.21	-.20	.00	3.70	.00	7.34	6.26
UTA	3	9	114	4.06	.00	-.19	-.57	3.58	.00	6.88	6.09
TEX	170	593	179	4.06	-.80	-.89	-1.12	5.62	.00	6.87	3.83
SDA	13	43	93	4.06	.00	.00	-.16	2.92	.00	6.82	7.44
NEB	18	68	108	4.06	-.24	-.27	-.29	3.39	.00	6.65	6.24
MIS	15	29	102	4.06	-.19	-.30	-.51	3.21	.00	6.26	6.23
LA	26	125	127	4.06	-.84	-.38	-.72	3.99	.00	6.10	4.86
WV	14	45	102	4.06	-.10	-.39	-.70	3.21	.00	6.08	6.06
ALA	15	56	111	4.06	-.58	-.53	-.40	3.50	.00	6.04	5.52
KAN	38	114	111	4.06	-.38	-.69	-.47	3.50	.00	6.01	5.49
TEN	25	169	153	4.06	-1.11	-.65	-1.23	4.80	.00	5.87	3.87
COL	17	140	111	4.06	-.60	-.87	-.25	3.50	.00	5.83	5.34
IA	41	130	102	4.06	-.28	-.31	-.95	3.21	.00	5.73	5.73
MIN	38	108	134	4.06	-.38	-1.46	-.74	4.20	.00	5.67	4.30
NC	39	176	94	4.06	-.30	-.31	-.83	2.96	.00	5.57	6.08
ORE	34	88	106	4.06	-.68	-.70	-.59	3.34	.00	5.42	5.23
SC	7	26	86	4.06	-.42	-.29	-.73	2.71	.00	5.33	6.41
ARK	15	44	111	4.06	-.97	-.57	-.66	3.47	.00	5.33	4.94
GA	48	188	115	4.06	-.70	-.72	-1.04	3.61	.00	5.20	4.64
FLA	131	435	156	4.06	-1.29	-.77	-1.73	4.89	.01	5.18	3.37
ME	13	26	88	4.06	-.78	-.35	-.59	2.77	.00	5.10	6.01
VA	21	87	98	4.06	-.90	-.58	-.65	3.08	.00	5.01	5.27
OKL	19	74	86	4.06	-.77	-.44	-.63	2.71	.00	4.94	5.95
WAS	31	81	92	4.06	-.61	-.95	-.61	2.88	.02	4.79	5.44
WIS	45	140	93	4.06	-.78	-.66	-.84	2.94	.04	4.77	5.30
KY	26	102	96	4.06	-1.51	-.59	-.72	3.01	.00	4.24	4.82
MO	45	167	123	4.06	-1.91	-1.15	-.77	3.85	.00	4.08	3.43
CAL	197	794	137	4.06	-1.57	-1.33	-1.42	4.32	.01	4.06	3.03
MIC	99	277	116	4.06	-1.75	-.93	-1.89	3.65	.05	3.19	2.8[illegible]
ILL	72	285	106	4.06	-.89	-1.78	-1.60	3.33	.06	3.18	3.14
NJ	146	484	129	4.06	-1.44	-1.51	-2.66	4.06	.63	3.13	2.51
PA	86	245	122	4.06	-2.23	-1.35	-2.68	3.84	.66	2.30	1.96
DEL	16	54	79	4.06	-2.45	-.93	-1.26	2.49	.05	1.97	2.70
IND	36	96	97	4.06	-2.71	-.88	-1.96	3.06	.13	1.70	1.86
CON	74	249	90	4.06	-2.73	-1.10	-2.26	2.84	.80	1.60	1.92
OHI	79	271	103	4.06	-3.06	-1.10	-2.38	3.23	.51	1.26	1.31

3.4 IMPACT OF 4D RNAV CAPABILITY ON ARRIVAL CAPACITY

The purpose of this analysis is to evaluate the impact of 4D RNAV capability on arrival runway capacity and, therefore, arrival delays through a comparison of 4D RNAV time-control capabilites with presently planned metering and spacing automation improvements. Metering and spacing techniques are intended to improve the degree of precision of control of interarrival spacing from final approach fix to runway threshold. If these spacings may be controlled more precisely, smaller values for the buffer distance required in addition to the nominal in-trail spacings to insure that the nominal spacings are not violated may be used. While these buffer values are not explicitly a part of control procedure, they exist in reality as the margin for error provided routinely in final approach control. As a result, the average interarrival spacing during periods of arrival saturation may be reduced if the precision to which threshold arrival time is controlled is improved.

Results of analytical studies and recent real time cockpit simulation and fast time simulation studies have shown that 4D RNAV techniques may be employed to significantly reduce arrival control error in comparison with the control error expected with advanced metering and spacing technology. The control error values found to be representative of open-loop control systems (M&S) are on the order of 10-15 seconds, while 4D RNAV has been shown to yield accuracies of approximately five seconds (one sigma). The discussion which follows derives the effect of such control error improvement on runway arrival capacity.

3.4.1 Runway Capacity Analysis

The techniques used for this analysis are based upon the relationships derived in Reference 24. That document describes the methods for quantifying arrival runway capacity covering a variety of conditions and assumptions. In order to keep the present analysis brief and oriented towards the primary problem of concern, the subject airport (San Francisco) was chosen in order to eliminate many of the complicating factors which impact arrival capacity. San Francisco serves a high volume of traffic, and under most circumstances all arrivals are served by one dedicated landing runway (28L), while departures are served by a dedicated runway of their own(1). The primary data sources used for the analysis concern the nature of the arrival traffic. Gross traffic data [25] were used for determining the overall traffic demand, while detailed data concerning the types of air carrier aircraft which serve SFO [26] and the scheduled arrival times[20] were used for determining runway capacity and to provide a baseline demand pattern for comparison with the capacity values determined to represent the cases of M & S, of improved control with 4D RNAV, and the baseline case of no arrival error.

In the present ATC environment, arrival runway capacity is limited primarily by the interarrival spacings required for IFR operations. The required spacings are three miles, or, for wake turbulence avoidance*, five miles for a light aircraft following a heavy transport, or four miles for

*Note that these separations have been further modified since this analysis was performed.

a heavy aircraft following a heavy aircraft [15]. The separation which results in terms of time is dependent upon the speeds of the the two aircraft of concern, and is significantly different depending on which aircraft is the faster. When the leading aircraft is faster, the minimum separation must be provided at the outer marker (five or six miles out), since the outer marker is the latest point at which a common path to the threshold can begin, and so the spacing at the threshold is longer. However, in the case where the trailing aircraft is faster, the minimum separation must be provided at the threshold. The minimum separation time, m, is [24]:

$$m\,(V_2,\, V_1) = \begin{cases} \delta_{12}/V_2 & \text{where } V_2 \geq V_1 \\ \delta_{12}/V_2 + \gamma\left(\dfrac{1}{V_2} - \dfrac{1}{V_1}\right) & \text{where } V_1 > V_2 \end{cases}$$

where:

m = Minimum required time separation at the threshold

V_1 = Speed of leading aircraft

V_2 = Speed of trailing aircraft

δ_{12} = Minimum separation (depending upon the aircraft types)

γ = Distance from outer marker to threshold

In order to apply the equation the characteristics of the arrival traffic at SFO must be determined. These characteristics include the mix of aircraft types and the final approach speed of each type (1.3 V_{so} was used for this analysis). Using the data from Reference 26 plus aircraft performance (stall speed) data for each aircraft type, the compilation of air carrier traffic shown in Table 3.25 was developed. Since no reliable data concerning GA activity other than total operation count was readily available, the distribution shown in Table 3.26 was used. The average traffic demand in FY71 [25] was 1032 itinerant operations, of which 815 (79%) were air carrier and 217 (21%) were general aviation. Applying these ratios to the data in Tables 3.25 and 3.26 yielded the overall distribution shown in Table 3.27. The percent distribution value for each speed class may be considered to be the probability that any given arrival aircraft is of the class indicated. These probabilities may be applied to the values for minimum separation time in such a manner that the average expected time separation for all arrivals may be computed. From the average separation, the average operations per hour (landing capacity) may be computed. The following relationships are derived in Reference 24:

$$s = pMp^T = \sum_{ij} p_i M_{ij} p_j$$

where s = Average expected time separation

p = Vector of probabilities, where $p = [p, p_2 \ldots . p_n]$

M = Matrix of minimum separation times

$M_{ij} = m\,(V_i, V_j)$

superscript T indicates matrix transpose

Runway capacity, c, is then the reciprocal of s.

Table 3.25 Air Carrier Arrival Traffic at SFO

Aircraft Type	Annual Arrivals	$1.5V_{so}$ (kt)	Landing Category*	Speed Class
707-100B	10032	153	D	5
707-300B	3846	144	D	4
707-300C	4633	144	D	4
720B	7570	151	D	5
727-100	12512	141	C	4
727-200	8481	148	C	4
737-200	15328	150	C	4
747	6032	156	D	7
DC-8-10/20/30	5103	157	D	5
DC-8-50	5710	162	D	6
DC-8-61	5398	166	D	7
DC-8-62	1494	166	D	7
DC-8-63	1696	166	D	7
DC-9-10	937	150	C	4
DC-9-15F	3	156	C	5
DC-9-30	3423	145	C	4
DC-10-10	2120	156	D	7
L-100-20	253	115	B	2
L-1011	224	148	D	7
CV-580	359	127	B	3
CV-880	1505	162	D	6
F-27	4108	105	B	1
TOTAL	100767			

Speed Classes:	Speed Range	Average Speed
1	$\leq$ 110 kt	105
2	$\leq$ 120 kt	115
3	$\leq$ 140 kt	128
4	$\leq$ 150 kt	145
5	$\leq$ 160 kt	155
6	> 160 kt	165
7	All Heavies ($\geq$ 300,000 lb)	160

* Category A. Speed 50-90 knots or weight 30,000 lbs. or less.
Category B. Speed 91-120 knots or weight 30,001-60,000 lbs.
Caterory C. Speed 121-140 knots or weight 60,001-150,000 lbs.
Category D. Speed 141-165 knots or weight over 150,000 lbs.

Table 3.26 General Aviation Traffic at SFO (Assumed)

Aircraft Type	Per Cent Distribution	Speed Class
Twin Piston	20%	1
Slow Turboprop	30%	2
Fast Turboprop	15%	3
Slow Turbojet	15%	3
Fast Turbojet	20%	4

Table 3.27 SFO Traffic Distribution

Speed Class	Per Cent Distribution	Average Approach Speed
1	7.43%	105 kt
2	6.50%	115 kt
3	6.59%	128 kt
4	42.74%	145 kt
5	17.80%	155 kt
6	5.65%	165 kt
7	13.29%	160 kt

Capacity was computed for the data given in Table 3.27. The resulting values are shown below:

$$p = [.0743 \quad .0650 \quad .0659 \quad .4274 \quad .1780 \quad .0565 \quad .1329]$$

$$M = \begin{bmatrix} 102.9 & 120.8 & 139.8 & 159.6 & 169.2 & 242.1 & 177.7 \\ 93.9 & 93.9 & 113.0 & 132.8 & 142.4 & 209.3 & 150.8 \\ 84.4 & 84.4 & 84.4 & 102.4 & 113.8 & 174.4 & 122.2 \\ 74.5 & 74.5 & 74.5 & 74.5 & 84.1 & 138.1 & 92.5 \\ 69.7 & 69.7 & 69.7 & 69.7 & 69.7 & 120.5 & 78.1 \\ 67.5 & 67.5 & 67.5 & 67.5 & 67.5 & 90.0 & 71.6 \\ 65.5 & 65.5 & 65.5 & 65.5 & 65.5 & 109.1 & 65.5 \end{bmatrix}$$

$s =$ 92.44 sec/operation, $c =$ 38.94 operations/hour

This result, 39 IFR operations per hour, is the arrival capacity of San Francisco based upon the assumption of zero time control error. There are, however, a few reasons why this estimate is believed to understate actual arrival capacity. First of all, during periods of high demand, controllers will often exercise a rudimentary form of speed class sequencing, which tends

to improve landing rate. Even more importantly, however, is the fact that controllers will often request slower aircraft to conduct their approach at a higher speed than desired. This not only increases overall average speed but also has the effect of speed class sequencing on arrival capacity. Although understated, the computed capacity value serves as a useful baseline for the following analysis of the impact of arrival time control error on landing capacity.

The effect of arrival time control error may be represented as an added buffer zone over and above the nominal in-trail separation requirement. The nominal size of this buffer zone is dependent upon three factors, presuming that the arrival control error tends to behave in a gaussian manner. These are the one-sigma values for control error, the desired degree of confidence in not exceeding the specified buffer zone, and the velocities of the aircraft involved. The equations for the buffer time are as follows [24].

$$b(V_2, V_1) = \begin{cases} \sigma_o \quad q(p_v) & \text{when } V_2 \geq V_1 \\ \text{Larger of 0 or} \left[\sigma_o\, q(p_v) - \delta_{12}\left(\frac{1}{V_2} - \frac{1}{V_1}\right)\right] & \text{when } V_1 > V_2 \end{cases}$$

where $b(V_2, V_1)$ = Buffer separation time

$\sigma_o q(p_v)$ = one-sigma control error value for the desired level of confidence P_v.

In that reference, the value used for P_v under present separation criteria is 5% (i.e. based on a 95% confidence level). The resulting value of $q(p_v)$ is 1.645, from standard cumulative distribution function tables for normal distributions. The average contribution of these buffer times may be found in a manner identical to that used previously for finding average separation time.

$$s_b = pBp^T = \sum_{ij} p_i B_{ij} p_j$$

where s_b = Average expected buffer separation

B = Matrix of Buffer separation times

$B = b\,(V_i, V_j)$

The runway capacity, c_t, is the reciprical of s_t, where:

$$s_t = s + s_b$$

$$c_t = \frac{1}{s+s_b}$$

In order to compute new values for total capacity, c_t, values for control error must be determined. The expected control error has been the subject of analytical studies, real time cockpit simulation studies, and fast time simulation studies. In Reference 27 the three cases of manual spacing, computer aided spacing and fully automated closed-loop spacing are analyzed. The expected interarrival errors determined were 20 seconds for manual control, 11 seconds for computer aided control, and 5 seconds for automated time control (one-sigma values). Actual cockpit simulator experiments using subject pilots [6] have been conducted recently which demonstrated that open-loop time control errors of 15.7 seconds (corresponding somewhat to the computer aided M & S case), and 4D RNAV time control errors of 5.4 seconds (one-sigma values) can be achieved. The open-loop technique used in those experiment was based upon the automated Metering and Spacing principle. However, a larger time control error (15.7 sec.) than expected (11 sec.) resulted due to the fact that M & S capabilities were not exercised to the greatest possible extent. Rather than to issue corrective vectors throughout maneuvers to the final approach course, the aircraft was allowed to proceed without a final correction vector (open-loop) after departing the last fix prior to final approach intercept. Therefore, the resulting time control errors are larger than those expected of a fully-implemented M & S system. In confirmation of the expected performance of 4D RNAV time control, a recent fast-time simulation study [28] of advanced 4D RNAV time control systems has shown that delivery error to the outer marker would be expected to be on the order of five seconds. Therefore, for purposes of this analysis, the error times determined in Reference 27 (20,11 and 5 seconds) will be used. The matrices of buffer separation times, B, for these three cases are as follows:

Case 1: σ_o = 20.0 seconds <u>Manual Control</u>

$$\sigma_o q(p_v) = 32.90$$

$$B = \begin{bmatrix} 32.90 & 23.95 & 14.42 & 4.43 & 0. & 0. & 0. \\ 32.90 & 32.90 & 23.36 & 13.47 & 8.66 & 0. & 4.44 \\ 32.90 & 32.90 & 32.90 & 23.00 & 18.20 & 4.78 & 13.98 \\ 32.90 & 32.90 & 32.90 & 32.90 & 28.10 & 21.26 & 23.87 \\ 32.90 & 32.90 & 32.90 & 32.90 & 32.90 & 29.27 & 28.68 \\ 32.90 & 32.90 & 32.90 & 32.90 & 32.90 & 32.90 & 30.85 \\ 32.90 & 32.90 & 32.90 & 32.90 & 32.90 & 32.90 & 32.90 \end{bmatrix}$$

s_b = 27.56, s_t = 92.44 + 27.56 = 120.00 seconds/operation

c_t = 30.0 operations/hour

Case 2: σ_o = 11.0 seconds <u>Metering and Spacing</u>

$$\sigma_o q(p_v) = 18.10$$

$$\begin{bmatrix} 18.10 & 9.16 & 0. & 0. & 0. & 0. & 0. \\ 18.10 & 18.10 & 8.56 & 0. & 0. & 0. & 0. \\ 18.10 & 18.10 & 18.10 & 8.23 & 3.40 & 0. & 0. \\ 18.10 & 18.10 & 18.10 & 18.10 & 13.30 & 6.46 & 9.07 \\ 18.10 & 18.10 & 18.10 & 18.10 & 18.10 & 14.47 & 13.88 \\ 18.10 & 18.10 & 18.10 & 18.10 & 18.10 & 18.10 & 16.05 \\ 18.10 & 18.10 & 18.10 & 18.10 & 18.10 & 18.10 & 18.10 \end{bmatrix}$$

$s_b = 13.86$, $s_t = 92.44 + 13.86 = 106.30$ seconds/operation

$c_t = 33.87$ operations/hour

Case 3: $\sigma_o = 5.0$ seconds <u>4D RNAV M & S</u>

$\sigma_o q(p_v) = 8.23$

$$\begin{bmatrix} 8.23 & 0. & 0. & 0. & 0. & 0. & 0. \\ 8.23 & 8.23 & 0. & 0. & 0. & 0. & 0. \\ 8.23 & 8.23 & 8.23 & 0. & 0. & 0. & 0. \\ 8.23 & 8.23 & 8.23 & 8.23 & 3.43 & 0. & 0. \\ 8.23 & 8.23 & 8.23 & 8.23 & 8.23 & 4.60 & 4.01 \\ 8.23 & 8.23 & 8.23 & 8.23 & 8.23 & 8.23 & 6.18 \\ 8.23 & 8.23 & 8.23 & 8.23 & 8.23 & 8.23 & 8.23 \end{bmatrix}$$

$s_b = 5.60$, $s_t = 92.44 + 5.60 = 98.04$ seconds/operation

$c_t = 36.72$ operations/hour

The values which have resulted for average buffer separation, s_b, are relatively independent of the factors discussed earlier which tended make the earlier error-free runway capacity number conservative. The only variable of significance which would affect the s_b computation is the desired value for buffer violation probability, p_v, for which 5% was used here.

The basic metering and spacing capability will improve capacity by 12.9%, from 30.00 to 33.87 operations per hour. The degree of improvement which results from improving arrival time control accuracy through the use of 4D RNAV is expressed by the increase in arrival capacity, from 33.87 to 36.72 operations per hour, an improvement of 8.4%. This is a very significant increase in runway capacity, particularly in view of the fact that no runway improvements or significant ATC automation improvements are involved in this comparison (both presume metering and spacing automation), but that the entire improvement is due to the addition of time-control navigation capability (4D) to the basic airborne 2D or 3D RNAV computer system.

The capacity improvement is put in perspective in Figure 3.14, which shows the three computed capacity values overlaid on a plot of the estimated total hourly arrival demand for San Francisco. The hourly demand data for

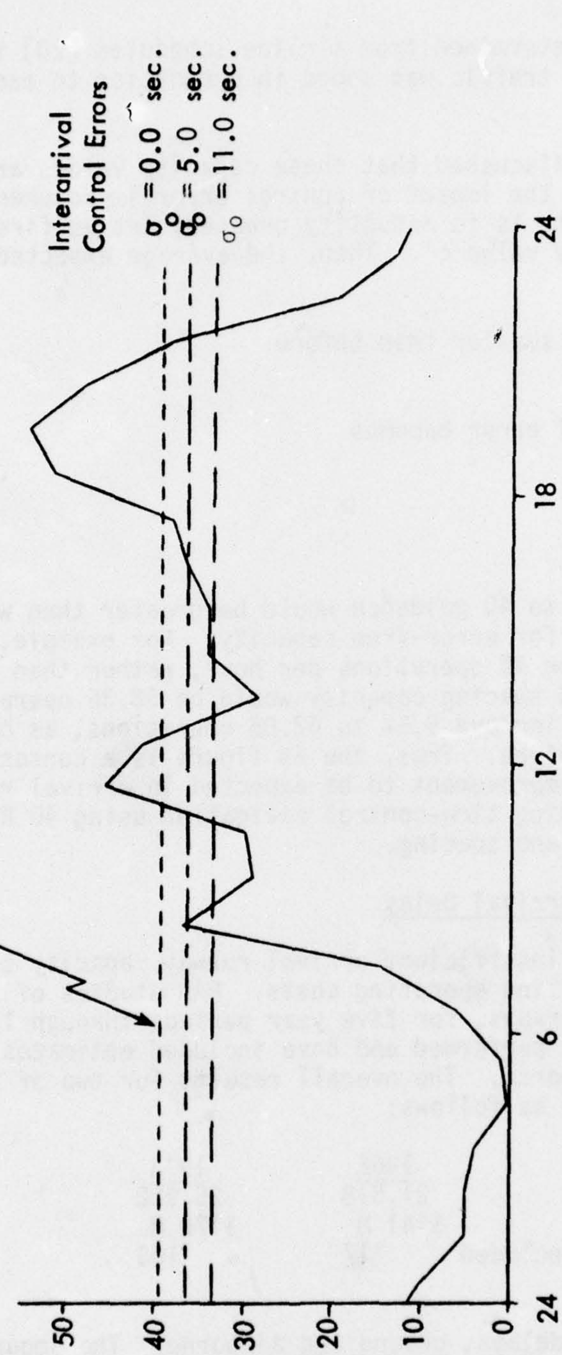


Figure 3.14 Arrival Operations at San Francisco

air carrier aircraft was determined from airline schedules [20] for a Friday in December, 1974. The GA traffic was added in proportion to each hours' data to get total demand.

Earlier the fact was discussed that these capacity values are probably understated. To determine the impact of control error improvements given that the error-free capacity is in actuality greater, let us first presume a greater error free capacity value c'. Then, the average expected time separation, s', becomes:

$s' = \frac{1}{c'}$, which is now smaller than before.

Total capacity with control error becomes

$$c'_t = \frac{1}{s' + s_b}$$

So the improvement from 2D to 4D guidance would be greater than was the case with the understated value for error-free capacity. For example, if that capacity were presumed to be 45 operations per hour, rather than 39, the computer-aided metering and spacing capacity would be 38.36 operations while the 4D RNAV capacity would improve 9.6% to 42.06 operations, as opposed to the 8.4% gain determined before. Thus, the 8% figure is a conservative estimate of the degree of improvement to be expected in arrival runway capacity as a result of adding time-control navigation using 4D RNAV guidance to computer aided metering and spacing.

3.4.2 Capacity Impact on Arrival Delay

Arrival delays due to insufficient arrival runway capacity constitute an important segment of airline operating costs. FAA studies of terminal area delays, based on airline surveys, for five year periods through 1969 [29] and through 1974 [30] have been performed and have included estimates of total airline delay at major airports. The overall results for two of the years within the time periods are as follows:

Year	1968	1973
Total Delay (K-min)	21,518	25,922
Delay Cost	$141 M	$176 M
Number of Airports Included	117	103

These include all terminal delays, ground and airborne. The amount of delay and related costs are expected to grow significantly as traffic growth rates continue to exceed airport capacity improvements. This, of course, is the primary motivation behind such development programs as Metering and Spacing, and Wake Vortex Avoidance. Data contained in these studies shows that approximately one-half the delay time is due to ATC causes (as reported by the airlines) and half is due to airport congestion (Table A-3 in Reference 30).

Nearly all of the ATC terminal delays are to arrival aircraft and so one-half of total delay appears as arrival holding and vectoring delay. In order to account for the occasional severe weather delays and so to consider only those normal, recurring delays due to demand temporarily exceeding normal IFR capacity, it has been assumed for purposes of this analysis that one-third of total terminal area delay is normal arrival holding delay which results from the natural capacity limitations of the runway configuration and arrival traffic type mix.

Nominal per-minute delay costs as used by the participating airlines are also reported in [30]. The costs stated are averages across the airline fleets. The values stated are (1974):

ATC delays	$9.46/minute
Airport delays	$6.54/minute
Total	$7.91/minute

The ATC delay costs are, of course, higher than airport delay costs since they occur while airborne (for the most part), while the airport delay cost are primarily ground delay-related. The $9.46 airline delay cost figure will be used in the following since it is consistent with data used elsewhere in this report and since it simplifies the analysis.

As explained in the previous section, the derived capacity figures understate actual arrival capacity at San Francisco. Therefore, it is desirable to determine approximately what the actual arrival capacity is under present circumstances. Once known, the improvements in capacity which would result from the implementation of M & S and 4D RNAV capabilities may be computed. After consideration of the several contributors to arrival delay, which include the inability to serve randomly arriving aircraft immediately due to the necessity of assembling them into an orderly final approach queue, and the quite sizeable impact of periods of temporary excess demand where aircraft must be held until approach slots are available, it was determined that temporarily excessive demand is far and away the largest cause of delays at airports where long delays are ordinarily experienced regardless of weather conditions. A straightforward model which uses hourly arrival rate data, such as shown in Figure 3.14, has been developed which computes total 24 hour delay based upon a presumed arrival capacity value. The model presumes that no aircraft are delayed when capacity exceeds demand. This assumption simplifies the model considerably, produces conservative results, and does not have a large impact on model accuracy when applied to the busier airports. When capacity is exceeded, that excess number of aircraft are delayed into the next hour where they are landed, and others are delayed if capacity is still exceeded. This process continues until demand decreases to the point where all waiting aircraft have been landed. For each problem studied, delay values are computed over a range of presumed capacity values so that a relationship of delay to capacity may be developed.

The model used to compute total daily delay operates by examining the number of arrivals scheduled for each hour, adding any surplus arrivals left over from the previous hour, computing delay for that hour and computing the number of aircraft left (if any) at the end of the hour. Daily delay is then the sum of the individual hourly delays. The relationships are as follows:

A = presumed hourly capacity

D_i = arrival demand for i^{th} hour

S_{i-1} = surplus from previous hour

δ_i = total delay during i^{th} hour (in hours)

if $D_i < A$:

SL_i = surplus arrivals landed in i^{th} hour

$$SL_i = \text{Min}\left[A - D_i \text{ or } S_{i-1}\right]$$

$$S_i = S_{i-1} - SL_i$$

$$\delta_i = \frac{SL_i^2}{2(A - D_i)} + S_i$$

if $D_i \geq A$:

$$S_i = S_{i-1} + D_i - A$$

$$\delta_i = S_{i-1} + \frac{D_i - A}{2}$$

δ = total daily delay = $\Sigma\delta_i$ (converted to minutes)

The first step towards ascertaining SFO IFR arrival capacity from the delay data in References 29 and 30 has been to run the model for demand values derived from the annual demand data presented in those studies. The delay-capacity results for those two cases are shown in Figure 3.15. The various total daily demand values have been modeled by modifying the arrival pattern shown in Figure 3.14 in direct proportion to the demand value. The data used were determined as follows, where air carrier operations are assumed to represent all IFR operations:

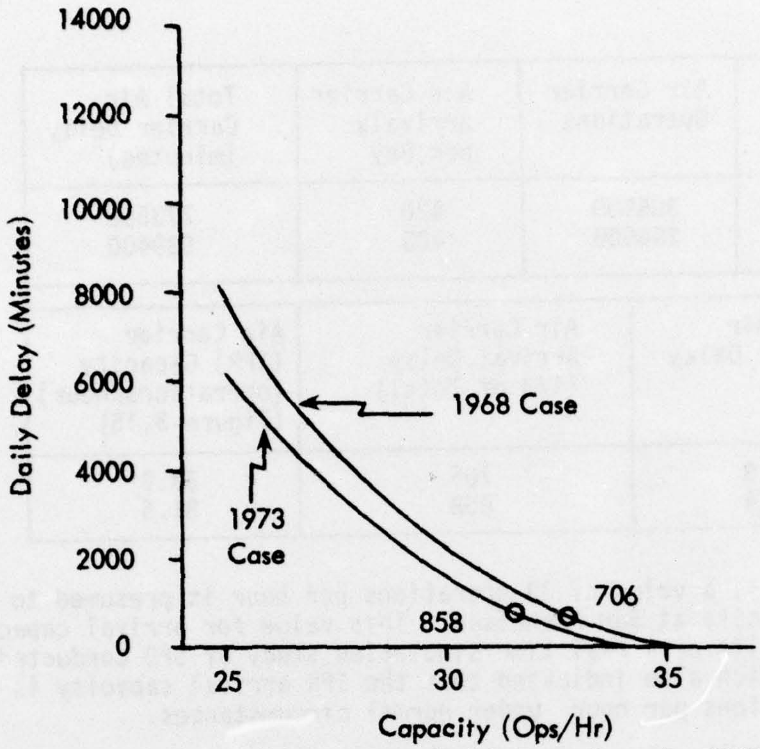


Figure 3.15 Delay Data Cases for SFO [29,30]

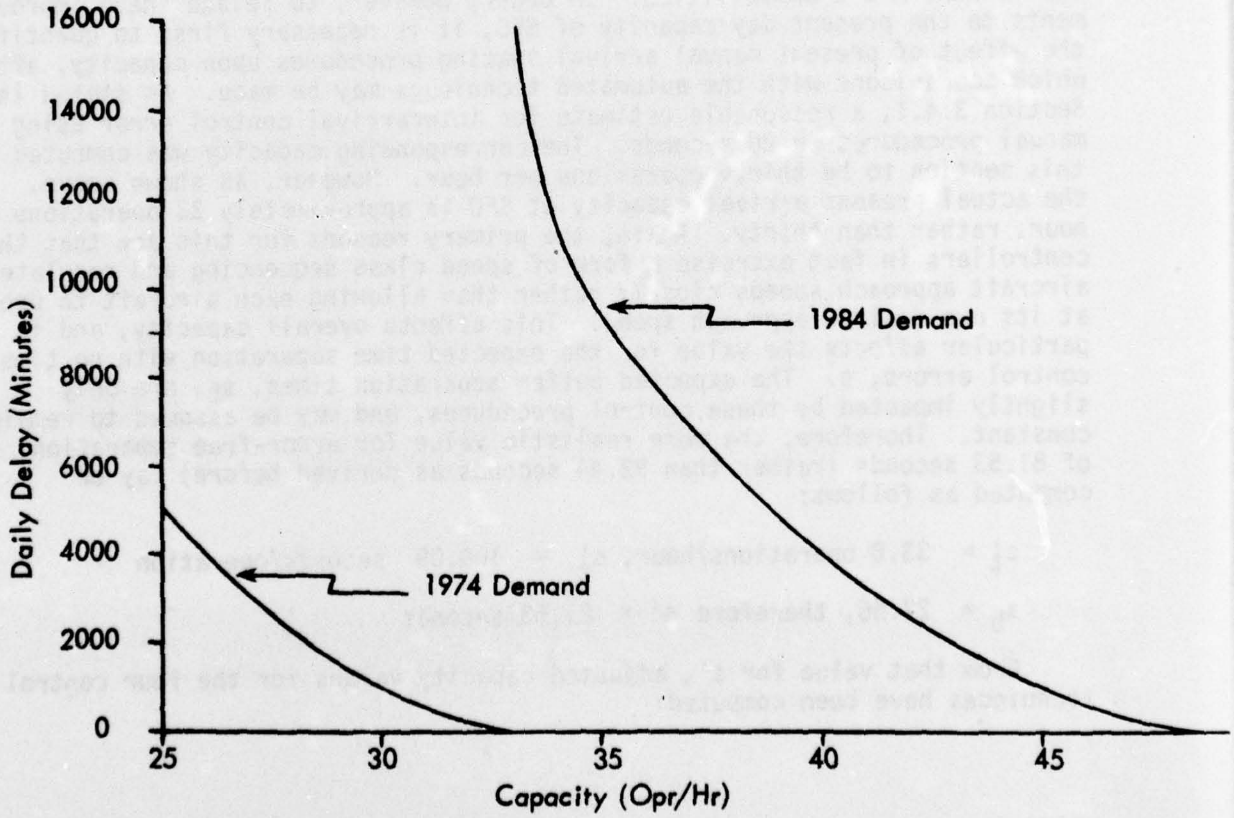


Figure 3.16 SFO Delay Projection for 1974 and 1984 Air Carrier Demand

Reference	Year	Air Carrier Operations	Air Carrier Arrivals per Day	Total Air Carrier Delay (minutes)
29 30	1968 1973	306900 294500	420 403	773500 939400

Year	Daily Air Carrier Delay	Air Carrier Arrival Delay (1/3 of Total)	Air Carrier (IFR) Capacity (operations/hour) (Figure 3.15)
1968 1972	2119 2574	706 858	32.9 31.5

Based upon these results, a value of 33 operations per hour is presumed to be the normal arrival capacity at San Francisco. This value for arrival capacity is verified by the results of a real time simulation study of SFO conducted at NAFEC in 1971[31] which also indicated that the IFR arrival capacity is approximately 33 operations per hour under normal circumstances.

Now that a reasonable estimate for San Francisco arrival capacity is available, it is possible to relate capacity increases to Metering and Spacing and 4D RNAV M & S capabilities. In order, however, to relate these improvements to the present day capacity of SFO, it is necessary first to quantify the effect of present manual arrival spacing procedures upon capacity, after which comparisons with the automated techniques may be made. As stated in Section 3.4.1, a reasonable estimate for interarrival control error using manual procedures in 20 seconds. The corresponding capacity was computed in this section to be thirty operations per hour. However, as shown above, the actual present arrival capacity at SFO is approximately 33 operations per hour, rather than thirty. Again, the primary reasons for this are that the controllers in fact exercise a form of speed class sequencing and regulate aircraft approach speeds closely rather than allowing each aircraft to proceed at its own desired approach speed. This affects overall capacity, and in particular affects the value for the expected time separation with no time control errors, s. The expected buffer separation times, s_b, are only slightly impacted by these control procedures, and may be assumed to remain constant. Therefore, the more realistic value for error-free separation, s', of 81.53 seconds (rather than 92.44 seconds as derived before) may be computed as follows:

$c_t' =$ 33.0 operations/hour, $s_t' =$ 109.09 seconds/operation

$s_b =$ 27.56, therefore $s' =$ 81.53 seconds

From that value for s', adjusted capacity values for the four control techniques have been computed:

Case	Time Error	Computed Capacity	Adjusted Capacity
Manual	20.0	30.0	33.0
M & S	11.0	33.9	37.7
4D RNAV	5.0	36.7	41.3
Ideal	0.0	38.9	44.1

What this table essentially says is that the theoretical arrival capacity at SFO given its runway conditions, traffic type mix and demand pattern is 44.1 operations per hour, while the imprecision of manual sequencing techniques reduces the effective capacity to 33 operations per hour, 25% less. This, of course, presumes that runway occupancy would not in fact constrain actual capacity below 44.1 operations, were that many able to land.

In order to establish the effect of these potential improvements on delays with present and projected traffic levels, demand data for 1974 and 1984 have been taken from the forecasts in Reference 32. These data have been used to provide daily air carrier arrival rates which were used as before as inputs to the delay-capacity model. The results of the model runs for each case are presented in Figure 3.16. The resulting delay values are as follows:

Case	Capacity	Daily Demand (No.of Arrivals)		Daily Delay (minutes)		Daily AC Cost (Dollars)		Annual AC Cost (Dollars)	
		1974	1984	1974	1984	1974	1984	1974	1984
Manual	33.0	397	575	50	15910	$0.5K	$150.5K	$0.2M	$54.9M
M & S	37.7	397	575	0	6124	0	57.9K	0	21.1M
4D RNAV	41.3	397	575	0	3038	0	28.7K	0	10.5M
Ideal	44.1	397	575	0	1459	0	13.8K	0	5.0M

The airline (IFR) delay costs are computed from the $9.46 per minute rate discussed earlier.

The results of this analysis are obviously quite significant. In 1984, 4D RNAV used in combination with Metering and Spacing capabilities can save $44,400,000 annually in terms of airline delay costs, while M & S alone could save $33,800,000. It is best at this time to review the assumptions used in arriving at these numbers in order to view them from the proper perspective.

a) Runway occupancy is not a limiting factor -- it is assumed that runway occupancy constraints would not be a limit for operations at the 4D rate (41.3/hour). This is reasonable since current limitations are due to the wake vortex and control error problems, not runway and taxiway problems.

b) No significant arrival runway improvements -- no significant runway improvements (other than taxiway improvements) are currently planned at SFO [46].

c) Peak flattening was not considered -- Peak flattening is inevitable as operation rates increase. Airlines would not tolerate the delay (27 min per arrival) shown in the 1984 figures without taking action to adjust schedules. Therefore the delay would be lower than that. However, other penalties would be suffered (lost revenue from contracted schedules and inconvenient arrival times) in the process, and so it is not unrealistic to considered non-peak-flattened delay as representing operating penalty for comparative purposes.

d) Traffic growth projections -- Latest available projection data is being used [32].

e) Aircraft buffer separation times are based on a 5% buffer violation probability -- If a larger value were presumed, M & S and 4D RNAV would make lesser improvements to overall delays, although unimproved delay values would remain the same.

In order to test the effect of the last assumption, the arrival rates and delay values have been recomputed presuming a 10% buffer violation probability. The results are as follows:

10% Buffer Violation Probability

Case	Capacity	Daily Demand (No.of Arrivals)		Daily Delay (minutes)		Daily AC Cost (dollars)		Annual AC Cost (dollars)	
		1974	1984	1974	1984	1974	1984	1974	1984
Manual	33.0	397	575	50	15910	$0.5K	$150.5K	$0.2M	$54.9M
M & S	36.4	397	575	0	7548	0	71.4K	0	26.1M
4D RNAV	38.8	397	575	0	5047	0	47.7K	0	17.4M
Ideal	40.7	397	575	0	3472	0	32.8K	0	12.0M

The total annual 4D RNAV with M & S savings for air carriers is now $37.5 million rather than $44.4 million, a decrease of 16% even though the allowable buffer violation probability has been doubled. To be conservative, 10% buffer violation probability figures will be used for the remainder of the analysis.

3.4.3 Capacity Impact at the Major U.S. Terminals

In order to be able to extrapolate the M & S and 4D RNAV M & S benefits over the major U.S. terminals, a simple procedure for estimating the delay/capacity relationships at other terminals has been developed. The only additional assumption required is that the average buffer separation time values, s_b, at the other terminals are similar to those at San Francisco. The s_b, values depend primarily on traffic type mix, which does not remain contant from terminal to terminal. However, the s_b values are not expected to change significantly.

The airports specifically studied here include Denver, Miami, Chicago, New York JFK, New York LGA, Newark and Philadelphia. In order to establish a

demand pattern for each airport, Reference 20 was used to obtain the air carrier arrival traffic sample (as illustrated in Figure 3.14 for SFO). The same procedure as before, using References 29 and 30, was used to estimate existing capacity at each of the seven airports. Then the projected capacity using Metering and Spacing and using 4D RNAV M & S was computed from the s_b values derived for San Francisco (based upon the 10% buffer violation probability level). Where more than one dedicated arrival runway exists (ORD & JFK, also MIA was modified to account for independent parallel runways with mixed operations) one-half of the s_b values were used in order to represent the split arrival situation. The results of these evaluations are presented as Table 3.28. In order to estimate, conservatively, the overall U.S. impact, estimates have been derived for the impact at the twenty-five highest delay airports in the U.S. [30]. The method used here for estimation was to determine the least-square exponential relationship of delay per operation as a function of 1984 daily air carrier arrival operations for each case: M & S versus manual control, and 4D RNAV with M & S versus manual control. The resulting curve fit relationships (Table 3.28) were applied to the twenty-five top delay airports, with the results given in Table 3.29. The values shown in Table 3.29 for the eight airports studied are curve fit values, which differ somewhat for each individual airport from the values in Table 3.28. However, by virtue of the curve fit process, the totals of either set of values for those eight airports are almost identical. The exponential relationship of total delay versus operations count was selected not only since it provided a reasonable result, but since the exponential relationship has been shown to properly fit substantial delay data compiled in other studies [65].

The 4D RNAV benefit column in Table 3.29 was computed as the difference of the other two values for which the curve fit technique was used. The total resulting 4D RNAV arrival delay benefit for the 25 high delay airports is $85,500,000 annually, based upon projected 1984 air carrier traffic levels.

Table 3.28 1984 Eight Airport Delay Projection (minutes)

Airport	Case	Daily A/C Arrivals	Estimated Capacity	Delay - Minutes: Daily Delay	Delay - Minutes: Delay per Operation	Savings-minutes: Savings per Operation: M&S	Savings per Operation: 4D	Savings per Operation: M&S + 4D
ORD	Manual	849	55.0	8040	9.47			
	M & S		59.7	813	0.96	8.51		
	4D		62.9	149	0.18		0.78	9.29
	Ideal		65.3	10	0.01			
JFK	Manual	488	42.0	5702	11.68			
	M & S		44.7	2564	5.25	6.43		
	4D		46.4	1443	2.96		2.30	8.73
	Ideal		47.8	865	1.77			
LGA	Manual	441	28.5	5946	13.48			
	M & S		31.0	2092	4.74	8.74		
	4D		32.8	447	1.01		3.73	12.47
	Ideal		34.1	112	0.25			
EWR	Manual	436	28.0	8220	18.85			
	M & S		30.4	4908	11.26	7.60		
	4D		32.1	2931	6.72		4.53	12.13
	Ideal		33.4	1683	3.86			
PHL	Manual	362	24.0	3033	8.38			
	M & S		25.8	876	2.42	5.96		
	4D		26.9	453	1.25		1.17	7.13
	Ideal		27.8	232	0.64			
MIA	Manual	432	33.0	5271	12.20			
	M & S		35.5	2805	6.49	5.71		
	4D		37.2	2107	4.88		1.61	7.32
	Ideal		38.5	1688	3.91			
DEN	Manual	421	29.0	7475	17.76			
	M & S		31.6	3802	9.03	8.72		
	4D		33.4	2608	6.19		2.84	11.56
	Ideal		34.8	1960	4.66			
SFO	Manual	575	33.0	15910	27.67			
	M & S		36.4	7548	13.13	14.54		
	4D		38.8	5047	8.78		4.35	18.89
	Ideal		40.7	3472	6.04			

Regression Equation: Savings/Operation = Ae^{Bx}, x = Arrivals

M & S: A = 1.16873, B = 0.0040863

M & S + 4D: A = 1.31224, B = 0.0044385

Table 3.29 1984 Annual Airline Arrival Delay Savings Projection

Airport	1984 Daily Airline Arrivals	Savings per Operation (Minutes)			Airline Annual Savings ($ Millions)		
		M&S	4D	M&S + 4D	M&S	4D	M&S + 4D
ORD	849	13.27	4.04	17.31	38.9	11.8	50.7
ATL	808	12.18	3.59	15.77	34.0	10.0	44.0
JFK	488	8.58	2.87	11.45	14.5	4.8	19.3
LGA	441	7.08	2.21	9.29	10.8	3.4	14.2
SFO	575	12.25	4.59	16.84	24.3	9.1	33.4
LAX	634	15.59	6.29	21.88	34.1	13.8	47.9
DEN	421	6.53	1.97	8.50	9.5	2.9	12.4
PHL	362	5.13	1.41	6.54	6.4	1.8	8.2
EWR	436	6.94	2.15	9.09	10.4	3.2	13.7
MIA	432	6.83	2.10	8.93	10.2	3.1	13.3
DAL/FTW	585	12.76	4.85	17.61	25.8	9.8	35.6
DCA	319	4.30	1.11	5.41	4.7	1.2	6.0
PIT	347	4.83	1.29	6.12	5.8	1.6	7.3
BOS	422	6.56	1.98	8.54	9.6	2.9	12.4
CLE	192	2.56	0.52	3.08	1.7	0.3	2.0
DTW	274	3.58	0.85	4.43	3.4	0.8	4.2
MSY	237	3.08	0.68	3.76	2.5	0.6	3.1
LAS	230	2.99	0.65	3.64	2.4	0.5	2.9
HNL	301	4.00	0.99	4.94	4.2	1.0	5.2
STL	356	5.01	1.36	6.37	6.1	1.7	7.8
FLL	110	1.83	0.31	2.14	0.7	0.1	0.8
TPA	158	2.23	0.42	2.65	1.2	0.2	1.4
MSP	205	2.70	0.56	3.26	1.9	0.4	2.3
SEA	182	2.46	0.48	2.94	1.6	0.3	1.9
BAL	151	2.17	0.39	2.56	1.1	0.2	1.3
TOTAL					265.8	85.5	351.3

25 Airport 4D RNAV Impact = $85,500,000

3.5 RNAV EQUIPMENT CAPABILITIES AND COSTS

This section investigates the capabilities offered by the spectrum of RNAV equipment presently available and the costs of each of these levels of capability, and relates system equipment costs to the several types of airspace users. Many existing RNAV systems do not meet proposed Minimum Operational Characteristics (MOC) requirements, and so the cost of providing such systems which do are estimated. Even though the total span of capabilities available is extremely broad, full 2D RNAV benefits are available to aircraft which equip with the most basic systems which meet MOC requirements.

3.5.1 RNAV Equipment Costs

This section considers the various levels of RNAV capability which are available and the incremental costs necessary to obtain each level. Both those minimum capabilities which will probably be required (Section 5.3), and additional capabilities which would serve to satisfy other user needs and desires are identified and cost estimates made. However, it should be recognized that each capability is not necessarily obtainable (or quantifiable) separately from all other capabilities since they typically come in groups or packages. All cost data were taken from published manufacturers' price lists.

For purposes of this analysis it is useful to separate capabilities into three type categories: functional capabilities, interface capabilities and data storage and management capabilities. The functional capabilities include the types of computations performed, modes of operation and output data generated. Interface capabilities include types of sensors usable with a system, compatible sensor manufacturers and models, and types of control systems and displays which can be driven. Data storage and management capabilities include multiple waypoint storage, automatic data entry, and mass data storage and retrieval. In detail, these capability levels are as follows:

Functional Capabilities

- Basic 2D area navigation capability
- Track angle computation
- 3D (VNAV) guidance capability
- 4D (time control) guidance capability
- Earth-oriented versus station-oriented computation
- Parallel offset capability
- Along track offset capability (VNAV mode)
- Direct-to-waypoint capability
- Approach mode sensitivity selection
- Slant range error compensation
- Computed data outputs (time to waypoint, ground speed, winds, command descent rate, etc.)
- Map display capability

Interface Capabilities

- VOR and DME interface
- Altimeter input (slant range error compensation)
- Altimeter input (3D RNAV)
- Air data input
- Multisensor capability (DME/DME, VLF, OMEGA, LORAN)
- ARINC system interfaces
- Non-ARINC interfaces, manufacturer and model limitations
- Display interface capabilities (CDI, HSI, RMI)
- Control system interface capabilities (flight director, autopilot)

Data Storage and Management Capabilities

- Single waypoint system
- Multiple waypoint storage
- Multiple waypoint storage with track storage and frequency selection
- Automatic data entry (cards, magnetized cards)
- Data conversion capability (rho/theta and lat/lon compatibility)
- Mass route data storage and retrieval

Each of the capabilities described above can impact RNAV system acquisition cost, although, as stated before, it is not always possible to separately list the incremental cost of each individual capability, and so costs must be estimated for functional groups of capabilities. Acquisition costs can also include costs of equipment other than the RNAV computer system. A prime example is the requirement for DME equipment, which not all affected general aviation aircraft would otherwise have. Also, VNAV capability, for example, requires that an altimeter compatible with the VNAV computer be available. In addition to equipment costs, there are other costs required for system installation and routine maintenance.

Tables 3.30 and 3.31 present matrices of RNAV system functional capabilities. Table 3.30 shows those capabilities which are normally available on existing basic systems, and the cost associated with these systems. Nearly all RNAV systems have certain basic capabilities, such as Distance to Waypoint and Cross Track Deviation computation, Enroute/Approach mode selection, normal VOR operating mode, normal localizer operation, direct-to waypoint navigation capability, and the ability to interface with RMI's, flight directors and autopilots (in some cases additional cost options are required for such interface capability). Different manufacturers provide different levels of compatibility with other manufacturer's sensors, with greater flexibility usually costing more. Lowest cost systems only interface with specific sensors manufactured by the same company. Functional capability increments available for basic RNAV systems include multiple waypoint capability and basic VNAV guidance. These systems typically are either analog or digital hybrid in mechanization.

In order to meet proposed MOC requirements, the basic system will be required to provide additional capabilities as shown below:

Basic RNAV System

Existing Capabilities	Additional MOC Capabilities
Station-oriented 2D RNAV, DTW, CTD computation, Approach/Enroute Modes, Direct-To Capability	Multiple Waypoint Storage, Parallel Offsets

In Table 3.30 the estimated costs of the Basic MOC System are given (with and without VNAV). These costs were estimated based upon the assumption of integral multiple way-point and parallel offset capabilities, not add-on packages.

More complex RNAV systems, which are summarized in Table 3.31, are of two basic types: complex station oriented systems and earth-oriented systems. Typically the former are of digital hybrid or all digital mechanical while the latter are all digital (except for required sensor signal processing for digitization). The station-oriented systems are intended for business and private aircraft applications and air taxi and commuter airlines, while the earth-oriented systems are intended mainly for airline applications. Note however that this is the present case and that there is no outstanding reason why a lower-cost earth-oriented system could not be developed, except that a Flight Data Storage Unit (FDSU) is almost a requirement for efficient system operation due to the large amount of information required for earth-oriented system operation. The FDSU would substantially increase system cost.

The capabilities which the complex station-oriented systems have over and above the basic systems include wind and ground speed computation, slant range correction, parallel offsets, dead reckoning capability and multiple waypoint, track bearing and station frequency storage. VNAV, with along track offset capability, is optional in some cases, standard in others. Some systems also have an Automatic Data Entry Unit available as an option. Earth-oriented systems possess the additional capabilities of operating in terms of latitude and longitude, performing track computation, operating with multiple sensor inputs, and operating with an FDSU (usually the FDSU is an option, although operation without it is difficult). More sophisticated systems also provide sophisticated control/display and data base management, including automatic station selection capability, at higher prices.

3.5.2 RNAV Equipment Costs for User Groups

The basic system requirements for the several types of aircraft operators are dictated by their types of operations and operational environment. Low altitude aircraft do not require slant range correction, and so may obtain RNAV capability through installation of basic MOC systems, whereas high altitude aircraft (including pressurized piston aircraft repeatedly involved

Table 3.30 Matrix of Basic RNAV Equipment Capabilities and Associated Costs

RNAV System Type	Functional Capabilities	Interface Capabilities	Data Management	RNAV Cost	Other Costs
BASIC SYSTEMS *					
Basic 2D RNAV	Station-oriented 2D RNAV, DTW, CTD computation, Approach/Enroute Modes, Direct-To Capability	VOR/DME,CDI, RMI, Flight Director, Auto-Pilot	Single Waypoint, Manual OBS	$2000	DME $2500 (where not equipped)
plus Multiple Way-points	---	---	Multiple Way-point	add $500/WP or $3000 for multi(10-16 WP) storage box	
plus 3D RNAV	Basic VNAV (VTD)	Altimeter, VDI, Flight Director, Autopilot	Manual Gra-dient & Alti-tude Select	add $1500	Altimeter $2000 to $5000
BASIC MOC SYSTEM:					
2D RNAV	Station-oriented 2D RNAV DTW,CTD, comput-ation, Approach/Enroute Modes, Direct-To Capability, Paral-lel Offset Capability	VOR/DME, CDI, RMI, Flight Director, Auto-Pilot	Multiple Way-point, Manual OBS	$3000	DME $2500 (where not equipped)
plus 3D RNAV	Basic VNAV (VTD)	Altimeter, VDI, Flight Director, Autopilot	Manual Gradient & Altitude Select	add $1500	Altimeter $2000 to $5000

*does not meet MOC

Table 3.31 Matrix of Complex RNAV Equipment Capabilities and Associated Costs

RNAV System Type	Functional Capabilities	Interface Capabilities	Data Management	RNAV Cost	Other Cost
COMPLEX STATION-ORIENTED SYSTEMS:					
2D RNAV System	Station-oriented RNAV, DTW, CTD,Wind,TTS,etc., Approach/Enroute Modes, Direct-To-Capabilities, Parallel Offsets, Slant Range Correction, Dead Reckoning Capability	VOR/DME, Altitude TAS, Compass, CDI, RMI, Flight Director Autopilot	10 waypoints, Track Bearings, Station Frequencies	\$10000 to \$18000	DME \$5000 (where not equipped)
plus 3D RNAV	VNAV along track offset	Altimeter, VDI, *Flight Director*	Manual Gradient & Altitude Select, Some Systems have integral VNAV	add \$2000	Altimeter \$2000 to \$5000
EARTH-ORIENTED SYSTEMS:					
Basic Systems	Earth-oriented 2D RNAV, Track Computation, DTW CTD, TAS, Wind,TTS,etc., VNAV,Along Track Offsets, Parallel Offsets, Slant Range Correction, Approach/Enroute Modes, Direct-To-Capability, Dead Reckoning Capability	VOR/DME Altitude Air Data Systems Multisensor Options CDI, RMI, Flight Director, Autopilot	Multiple Waypoint Storage	\$20000 to \$25000	
plus ADEU or FDSU	(above)	(above)	ADEU/FDSU	add \$10000 to \$150000	
Sophisticated Data base System (with FDSU)	(above) plus Automatic Station Selction	(above)	Sophisticated Data Base and Control/Display Unit	\$80000 to \$100000	
plus CRT Map Display	----	CRT Map Output	---	add \$35000	

in operations in metropolitan terminal areas) would probably obtain multiple waypoint capability to ease cockpit workload. Airline aircraft, repeatedly flying the same route structure, would in most cases obtain dual systems capable of storing entire route structures, such as the earth-oriented systems. Table 3.32 lists the typical minimum RNAV equipment costs for several aircraft classes, based upon the costs in Tables 3.30 and 3.31. DME and VOR costs are listed in order to obtain total cost for RNAV equipage for aircraft not presently possessing those capabilities.

Table 3.32 Minimum RNAV Capability Equipment Costs

Aircraft Category	Minimum Equipment Cost			Required Capability
	RNAV	DME	VOR	
Single Engine, < 4 places	$ 3000	$2500	$2000	Basic MOC RNAV
Single Engine, ≥ 4 places	3000	2500	2500	
Multi-Engine, < 12,500 lb	5000*	5000	2500	Multiple Waypoint
Multi-Engine, ≥ 12,500 lb	5000*	5000	--	
Turboprop, < 12,500 lb	10000	5000	--	Slant Range Correction
Turboprop, > 12,500 lb	10000	5000	--	
Turbojet	10000	5000		
Turbojet (Air Carrier)	60000	--	--	FDSU, Dual Installation

* Pressurized, high altitude multi-engine aircraft would require slant range correction.

This section discusses the fleet equipage costs for the three basic user groups: air carrier aircraft, business aircraft and non-business GA aircraft. It is assumed that all air carrier jet aircraft will be equipped with dual RNAV installations, whereas business jet and turboprop aircraft are assumed to be equipped with single installations, although many would be expected to be dual equipped. Other GA aircraft are treated separately in a parametric manner based upon several candidate levels of RNAV requirement.

The projected 1984 civil aircraft fleet is listed below, based upon estimates taken from Reference 33.

Air Carrier	Business GA			Non-Business GA		
(All)	(Turbine)	(Recip-Multi)	(Recip-Single)	(Turbine)	(Recip-Multi)	(Recip-Single)
3,100	6550	21550	38500	1250	8250	135900

3.5.2.1 Air Carrier Costs

It is indicated above that there are projected to be 3100 air carrier aircraft in 1984. Table 3.32 lists a cost of $60,000 as being the minimum cost required to outfit each air carrier aircraft with dual RNAV installations. Based upon these figures, the one-time cost required to outfit the entire 1984 fleet would be on the order of $186 million.

3.5.2.2 Business and Other General Aviation Costs

To the General Aviation segment, and particularly the business aircraft operators, it is of significant interest to know the impact which a requirement for RNAV for operations in certain airspace would have on user costs for equipment. Likewise, that cost is of interest to the FAA when making such an airspace-restriction decision. Two basic classifications of such airspace which would be affected by RNAV are the high altitude environment and certain terminal areas.

High Altitude

According to RNAV Task Force guidelines and the implementation plan proposed in this report, RNAV would eventually be required in the high altitude environment and in certain terminal areas. The minimum cost of equipping the existing high altitude GA fleet is listed in Table 3.33. The aircraft counts in Table 3.33 represent estimates of fleet size as of May 1975 and were derived in the manner discussed in the following sections.

Table 3.33 High Altitude GA Fleet Equipage Cost ($ Millions) for Existing Fleet

A/C Type	A/C Affected	RNAV Eqpd.	Remainder	No DME	No VOR	Cost
Multi ≥ 12,500 lb	646	80	566	193	---	$3.80M
Turbo < 12,500 lb	1336	396	940	39	---	9.60
Turbo ≥ 12,500 lb	264	61	203	5	---	2.06
Turbojet	1200	377	823	12	---	8.29
TOTAL:	3446	914	2532	249	---	$23.75M

These numbers in Table 3.33 are projected into 1984 and broken down into business operators and non-business operators through use of the projected fleet data stated earlier, as shown in Table 3.34.

Table 3.34 High Altitude GA Fleet Equipage Cost ($Millions) for 1984 Fleet

A/C Type	Business A/C Number	Business A/C Cost	Non-Business A/C Number	Non-Business A/C Cost
Turbine	6550	$46.7M	1250	$8.9M
Multi ≥ 12,500	467	2.7	179	1.1
Total	7017	$49.4M	1429	$10.0M

(Note: Piston Multi ≥ 12,500 lb numbers were not increased from 1974 to 1984 levels since they are no longer being manufacturered)

Terminal Area

In order to determine the cost impact of requiring RNAV capability for entry into terminal area airspace (as transponders and altitude reporting capability are now required at some terminals), it is necessary to make some assumptions regarding the airspace to be so set aside. Therefore, this cost study has been performed in a parametric manner in order to present user cost data in a form which shows the effects of including progressively more airspace as requiring RNAV capability. Given that the airspace serving a particular airport is set aside requiring RNAV capability for entrance, the user impact can only be determined from knowledge of the numbers of each type of aircraft which operated at that particular airport. Since this information was not available, a substitute source of like information was sought. The Aircraft Registration Master File, maintained by FAA through the use of annual aircraft registration questionnaires, contains information concerning aircraft type, base airport, and avionics complement for each registered aircraft in the United States. The base airport data was used for this analysis as representative of the airport at which the aircraft operates. Naturally, this would understate the number of aircraft of each type which would operate at any given airport, since common destination airports are not included. However, this does represent a certain subset of total operations; appropriate multipliers may be estimated to attempt to determine the total effect for any given case.

The registration file of May, 1975 was used to provide the most recent data available. This file contains just short of 200,000 aircraft of which 140,000 have been estimated to be currently certificated and active (References 22,34,35,36 contain historical active aircraft data from which the estimates were made). A search of the file has yielded 110,000 aircraft as showing active status. The remaining thirty thousand are shown as inactive on that tape since the 1975 registration questionnaires for them had not yet been processed. The numbers of aircraft in each category at each airport were adjusted upward to account for this discrepancy. The resulting tables contained the numbers of each type of aircraft which was fitted with a given avionics complement, at each group of airports selected.

Eight categories of airports were selected for the parametric analysis: Primary airports at high density hubs (as defined by the Task Force) and airports within fifteen, thirty and forty-five miles of the center of each high density hub, and medium density hub airports and airports within fifteen, thirty and forty-five miles of them. The analysis of costs required to RNAV-equip each aircraft based within a certain group of airports was performed by counting the total number of aircraft of each type (e.g., Single Engine, four place or greater) and subtracting the number which are presently RNAV-equipped. This remainder was multiplied by the appropriate equipment cost (Table 3.32). Then the numbers of aircraft which are presently DME equipped or VOR equipped were multiplied by their appropriate costs, with all results summed to yield total cost for RNAV equipage at the particular set of airports of interest. The results are presented in Tables 3.35 (high density hubs) and 3.36 (medium density hubs). These results are given for single engine aircraft, by seating capacity, and for light twins. Other (high altitude) aircraft have been treated separately in Table 3.33. Note that

the cost figures listed in each of Tables 3.35 and 3.36 are not additive; that is to say that each category (e.g., within 30 nm) contains all aircraft within the previous category (within 15 nm). The numbers in these tables understate somewhat the actual costs since they do not include aircraft based outside of such terminal areas which conduct operations within such areas in the normal course of business. Also, some aircraft listed in the Aircraft Registration Master File do not indicate a base airport (1730), some are not based at an established airport (10023), and some reported a non-standard or unidentifiable airport (3840), out of the 140,000 active aircraft. The degree to which the equipage costs are understated is greater for the case of hub airports only, and becomes lesser as more airports are included.

Based upon the fleet forecasts stated earlier the data in Tables 3.35 and 3.36 may be projected to 1984 levels, and expressed in terms of business and non-business usage as shown in Table 3.37.

Since the cost of requiring RNAV capability in certain airspace could in some cases be a burdensome requirement, it is possible to approach the design of RNAV terminal airspace from a Terminal Control Area point of view. That approach is to require that only a small radius of airspace around each major terminal be restricted to aircraft with certain capabilities at ground level; hence, only operators at the major hub airport (and in a few cases other very close airports) would be required to be so equipped. The radius of airspace so affected becomes larger at higher altitude levels, but is terminated at a fixed altitude (usually 7000 or 8000 feet) to allow VFR flyovers. An example of a TCA is illustrated in Figure 3.17, which is taken from the Airman's Information Manual. In that figure the altitude bounds of each segment of the TCA are given. The only airport affected by the ground level requirement (inner circle) is the major hub airport (Boston Logan). Operations may be conducted at other nearby airports without affecting the TCA airspace, and so operators at those airports need not have the avionics capabilities required at the major hub airport(s).

The cost of equipping business and non-business general aviation aircraft, based on 1984 fleet size, is summarized in Table 3.37. The cost of equipping these aircraft for operation only in the high altitude structure, plus at high and medium density hub airports (through implementation of a TCA concept at these airports) is given in Table 3.38. In that table, it is presumed that all operators (IFR and VFR) would be required to have RNAV capability. The results shown are quite significant, in that the minimum requirement for achieving the major portion of all RNAV benefits may be realized by requiring RNAV in the high altitude airspace and at the twenty major terminal hub airports and the forty medium density hub airports, and that the one-time cost involved for business operators would be $66.4 million, and for non-business operators would be $37.3 million, only fractions of the total annual benefits to all users. And, most of those GA operators who would be required to equip would also be in a position to derive significant RNAV benefits as a result.

Table 3.35 RNAV Equipage Costs at High Density Terminal Hubs for Existing Fleet

A/C Class	A/C Affected	With RNAV	Remainder	No DME	No VOR	Cost
	At High Density Hub Airports:					
Single Engine < 4 Places	964	21	943	874	79	$ 4.11M
Single Engine ≥ 4 Places	2266	139	2127	1705	11	8.53
Multi Engine ≤ 12,500 Lbs.	766	99	667	140	0	4.04
TOTAL	3996	259	3737	2719	90	$16.58M
	Within 15 nm of High Density Hubs:					
Single Engine < 4 Places	2581	86	2495	2200	344	$11.18M
Single Engine ≥ 4 Places	5522	371	5151	4245	46	21.00
Multi Engine ≤ 12,500 Lbs.	1729	240	1489	334	11	9.14
TOTAL	9832	697	9135	6779	401	$41.32M
	Within 30 nm of High Density Hubs:					
Single Engine < 4 Places	5004	158	4846	4219	715	$21.69M
Single Engine ≥ 4 Places	10288	688	9600	7973	82	39.39
Multi Engine ≤ 12,500 Lbs.	3102	458	2644	554	20	16.05
TOTAL	18394	1304	17090	12746	817	$77.03M
	Within 45 nm of High Density Hubs:					
Single Engine < 4 Places	8070	281	7789	6601	1380	$34.84M
Single Engine ≥ 4 Places	15152	1011	14141	11909	136	58.33
Multi Engine ≤ 12,500 Lbs.	4207	606	3601	781	26	21.99
TOTAL	27429	1898	25531	19291	1542	$115.16M

Table 3.36 RNAV Equipage Costs at Medium Density Terminal Hubs for Existing Fleet

A/C Class	A/C Affected	With RNAV	Remainder	No DME	No VOR	Cost
	At Medium Density Hub Airports:					
Single Engine < 4 Places	399	10	389	370	18	$ 1.74M
Single Engine ≥ 4 Places	1329	91	1238	985	11	4.96
Multi Engine ≤ 12,500 Lbs.	864	175	689	94	7	3.93
TOTAL	2592	276	2316	1449	36	$10.63M
	Within 15 nm of Medium Density Hubs:					
Single Engine < 4 Places	2371	76	2295	1940	402	$10.24M
Single Engine ≥ 4 Places	4779	318	4461	3708	62	18.32
Multi Engine ≤ 12,500 Lbs.	1803	315	1488	269	11	8.81
TOTAL	8953	709	8244	5917	475	$37.37M
	Within 30 nm of Medium Density Hubs:					
Single Engine < 4 Places	3494	116	3378	2681	781	$15.02M
Single Engine ≥ 4 Places	6284	409	5875	4980	88	24.38
Multi Engine ≤ 12,500 Lbs.	2064	352	1712	333	11	10.25
TOTAL	11842	877	10965	7994	880	$49.65M
	Within 45 nm of Medium Density Hubs:					
Single Engine < 4 Places	5585	165	5420	4154	1383	$23.99M
Single Engine ≥ 4 Places	9391	626	8765	7532	137	36.63
Multi Engine ≤ 12,500 Lbs.	2742	462	2280	462	14	13.75
TOTAL	17718	1253	16465	12148	1534	$74.37M

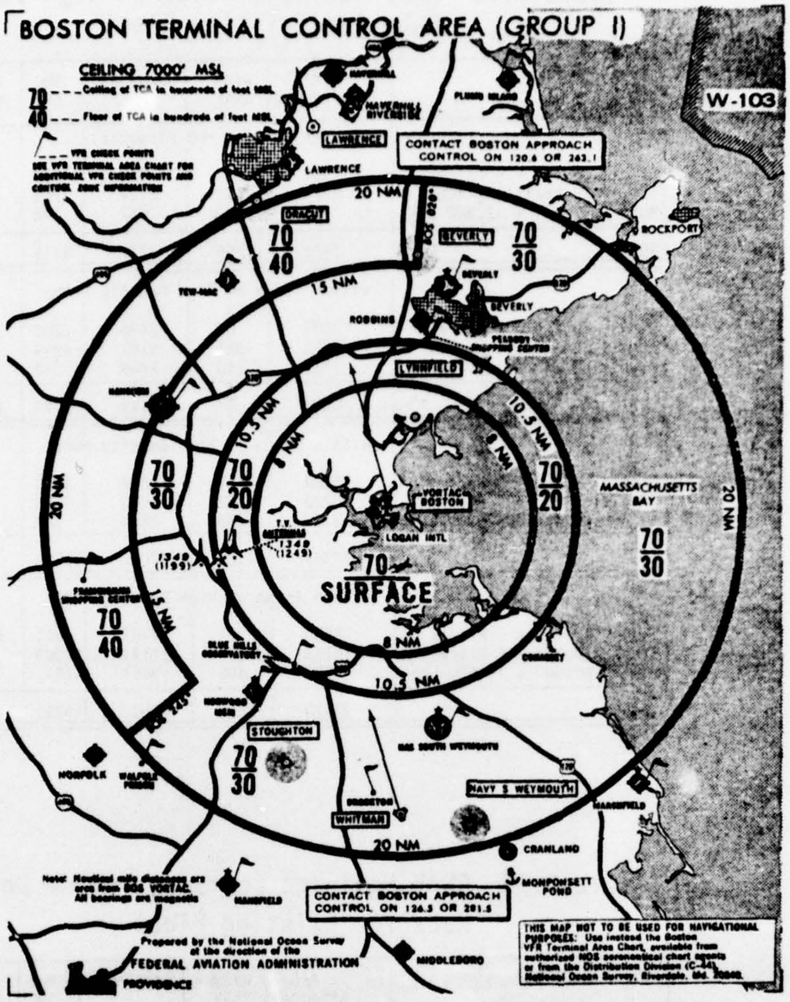


Figure 3.17 Boston Terminal Control Area

Table 3.37 Summary of 1984 Terminal Area RNAV Equipage Costs

	High Density Hubs		Medium Density Hubs	
	Business	Non-Business	Business	Non-Business
Hub Airports	$ 9.58M	$17.23M	$ 7.41M	$10.03M
Within 15 nm	22.91	43.29	21.24	38.77
Within 30 nm	41.79	81.52	26.82	52.54
Within 45 nm	60.49	123.11	38.63	79.82

Table 3.38 RNAV GA Requirement 1984 Cost Summary - TCA Concept, Terminal and Enroute

Requirement	Business Operators	Non-Business Operators
High Density Hub Airports Only	$ 9.58M	$17.23M
Medium Density Hub Airports Only	7.41	10.03
TOTAL TERMINAL	$16.99M	$27.26M
High Altitude GA Operators	49.4	10.0
TOTAL GA	$66.39M	$37.26M

3.6 INDIVIDUAL AIRLINE BENEFITS

A set of computer programs has been developed for purposes of evaluating the benefits which RNAV usage can provide for individual airlines. In order to provide a complete analysis of potential RNAV benefits, the entire route structure of a subject airline is analyzed in order to determine benefits in the enroute and terminal phases of flight, and to isolate 3D (VNAV) and 4D (time control) benefits in arrival operations.

3.6.1 Data Sources

The basic source of data for an airline RNAV benefits analysis is the airline schedule. The basic items of interest are, for each scheduled flight, the origin and destination city, the frequency of service (daily, etc.), and the type of aircraft used. All of this information is available in the Official Airline Guide (OAG) listings [20]. These data were utilized to create files of identical form for each of six (6) airlines. All flight segments either originating or terminating at non-CONUS airports were deleted from the files.

A data base concerning performance for several popular aircraft types (B-747, DC-10-10, DC-8-63, B-727-100, DC-9-30) was generated from manufacturer's aircraft performance data handbooks. The basic items of interest were true airspeed and fuel consumption rate under typical cruise conditions. However, selected cruise altitude is strongly influenced by the range between city-pairs, since it is not economical to climb to maximum cruising altitude on the shorter range flights. Tables of optimum cruise altitude as a function of intercity distance were generated during an earlier study [12], and so were used here. For each airline city-pair in the airline schedule file, the intercity distance was determined in one of two ways: If the city-pair had been evaluated for RNAV benefits (if included in the NAFEC route structure), the enroute distance was taken from the RNAV benefits file (explained later), to which ninety (90) miles were added, representing terminal distance, to estimate intercity distance; If the city-pair were not included in the NAFEC design, intercity distance was computed by looking up the latitude/longitude of each airport in an airport coordinates file created for this purpose, and using great circle equations to find distance. Only those city-pairs represented in the NAFEC structure were evaluated directly for RNAV benefits by this program. In these cases the intercity distance estimate was used in a lookup table for the particular aircraft type to find optimum cruise altitude, and corresponding fuel and time consumption parameters. These parameters were multiplied by the RNAV route length benefit for that route to get fuel and time saved. These values were then multiplied by flight frequency to get annual RNAV benefits for that city-pair for that flight. Enroute distance taken from the RNAV benefits file was also multiplied by flight frequency to get annual route miles for that city-pair for that flight. In those cases where the city-pair was not in the NAFEC structure, enroute distance was estimated by subtracting ninety (90) miles from the computed intercity distance. However, no cruise altitude was

estimated since no estimated RNAV benefit was available. Instead, annual RNAV time and fuel benefits and annual RNAV route miles were aggregated over the various routes; also, annual route miles for those segments not in the NAFEC structure were aggregated separately. In this manner, total annual flight mileage on NAFEC structure routes is known for each aircraft type, and therefore the RNAV benefits achieved on the NAFEC structure could be extrapolated to an entire airline's route structure, presuming that the final operational RNAV route structure expected to be implemented would serve all of the airline's routes.

In order to accommodate the several jet aircraft types in operation other than those five types analyzed, conversion factors were derived for each type which compensated for cruise speed and fuel consumption differences among the various types. For each aircraft type, the most similar aircraft for which data existed was selected as the baseline (e.g. the B-737 used the DC-9-30 as its baseline). Data for deriving conversion factors for each model were obtained from the operational fuel consumption/block speed reports collected by the CAB [37].

3.6.2 Enroute 2D RNAV Benefits

The basic enroute RNAV benefits file was constructed to show net enroute distance benefit for each city-pair represented in the NAFEC structure. The file contained origin and destination airport codes, RNAV benefit and VOR enroute route length. The net RNAV benefit was taken from the results derived at NAFEC [4], as modified by the weather routes study (Section 3.2.1) and the restricted areas study (Section 3.2.2).

The enroute RNAV benefits for each city-pair for each airline studied are shown in Tables G.1 through G.6 in Appendix G. A sample of the results for Eastern Airlines are shown in Table 3.39. In the first entry of that table, the origin airport (ATL-Atlanta) code, followed by the destination code (BAL-Baltimore), is followed by the EAL flight number (126). Subsequently, the enroute distance (388.0 nm) and RNAV benefit (14.00 nm), taken from the RNAV benefits file, are listed. The aircraft type is the stretched DC-9 (D9S). Flight frequency is daily (7 days/week). The typical cruise altitude derived directly from the intercity distance is 34480 feet. Naturally, this is an unrealistic altitude since flight levels at four thousand (4000) foot increments are assigned. However, the odd value derived represents a reasonable <u>average</u> flight level given the various flight levels which would be assigned over a period of time. The last two items listed are the RNAV benefits in terms of time saved (minutes) and fuel saved (gallons).

3.6.3 Terminal 2D RNAV Benefits

The primary data sources used in the analysis of the terminal area 2D RNAV benefits are the results of the analyses in Section 3.1.1, where per-operation RNAV benefits for eight (8) aircraft types at nine (9) large airports are derived. Also, methods of extropolating these benefits to forty-nine (49) other airports were developed. Individual airline terminal 2D

TABLE 3.39
EASTERN AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
ATL	BAL	126	338.0	14.00	D9S	7	34480.	1.89	23.45
ATL	BAL	132	338.0	14.00	D9S	7	34480.	1.89	23.45
ATL	BAL	134	338.0	14.00	D9S	7	34480.	1.89	23.45
ATL	BAL	136	338.0	14.00	D9S	1	34480.	1.89	23.45
ATL	BAL	138	338.0	14.00	D9S	7	34480.	1.89	23.45
ATL	BAL	424	338.0	14.00	727	1	35000.	1.83	32.05
ATL	BAL	434	338.0	14.00	72S	6	35000.	1.85	35.00
ATL	BNA	244	98.0	1.00	D9S	7	27640.	.13	1.95
ATL	BNA	620	98.0	1.00	72S	7	25640.	.13	3.06
ATL	BNA	624	98.0	1.00	72S	7	25640.	.13	3.06
ATL	BNA	670	98.0	1.00	72S	7	25640.	.13	3.06
ATL	BNA	676	98.0	1.00	D9S	7	27640.	.13	1.95
ATL	BOS	116	770.0	6.00	727	7	35000.	.78	13.74
ATL	BOS	128	770.0	6.00	L10	7	41000.	.74	26.78
ATL	BOS	148	770.0	6.00	727	6	35000.	.78	13.74
ATL	BOS	534	770.0	6.00	727	7	35000.	.78	13.74
ATL	BUF	330	535.0	4.00	727	7	35000.	.52	9.16
ATL	BUF	632	535.0	4.00	72S	7	35000.	.53	10.00
ATL	BUF	962	535.0	4.00	L10	7	41000.	.49	17.85
ATL	CLT	322	116.0	8.00	727	7	27080.	1.01	21.43
ATL	CLT	324	116.0	8.00	D9S	7	29040.	1.05	15.01
ATL	CLT	348	116.0	8.00	D9S	7	29040.	1.05	15.01
ATL	CLT	360	116.0	8.00	72S	7	27080.	1.02	23.41
ATL	CLT	476	116.0	8.00	72S	7	27080.	1.02	23.41
ATL	CLT	652	116.0	8.00	72S	7	27080.	1.02	23.41
ATL	DCA	130	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DCA	146	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DCA	380	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DCA	904	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DFW	135	555.0	1.00	DC9	7	35000.	.13	1.57
ATL	DFW	451	555.0	1.00	DC9	7	35000.	.13	1.57
ATL	DFW	523	555.0	1.00	727	7	35000.	.13	2.29
ATL	DFW	573	555.0	1.00	D9S	7	35000.	.14	1.66
ATL	DFW	577	555.0	1.00	727	7	35000.	.13	2.29
ATL	EWR	106	585.0	4.00	727	7	35000.	.52	9.16
ATL	EWR	110	585.0	4.00	727	7	35000.	.52	9.16
ATL	EWR	112	585.0	4.00	72S	6	35000.	.53	10.00
ATL	EWR	112	585.0	4.00	72S	1	35000.	.53	10.00
ATL	EWR	911	585.0	4.00	L10	7	41000.	.49	17.85
ATL	GSO	362	178.0	0.00	D9S	7	31347.	0.00	0.00
ATL	GSO	368	178.0	0.00	72S	7	31027.	0.00	0.00
ATL	GSO	580	178.0	0.00	D9S	7	31347.	0.00	0.00
ATL	GSO	682	178.0	0.00	72S	7	31027.	0.00	0.00
ATL	JAX	86	146.0	-6.00	727	7	29320.	-.76	-15.16
ATL	JAX	231	146.0	-6.00	72S	7	29320.	-.77	-16.56
ATL	JAX	397	146.0	-6.00	727	7	29320.	-.76	-15.16
ATL	JAX	533	146.0	-6.00	D9S	7	30240.	-.79	-10.94
ATL	JAX	578	146.0	-6.00	D9S	7	30240.	-.79	-10.94
ATL	JAX	677	146.0	-6.00	72S	7	29320.	-.77	-16.56
ATL	JFK	108	691.0	4.00	727	7	35000.	.52	9.16
ATL	JFK	444	691.0	4.00	DC9	7	35000.	.53	6.27
ATL	LAX	83	1642.0	17.00	727	7	35000.	2.22	38.92
ATL	LAX	87	1642.0	17.00	727	6	35000.	2.22	38.92
ATL	LAX	87	1642.0	17.00	727	1	35000.	2.22	38.92
ATL	LAX	89	1642.0	17.00	727	7	35000.	2.22	38.92
ATL	LGA	80	567.0	4.00	727	7	35000.	.52	9.16
ATL	LGA	100	567.0	4.00	D9S	7	35000.	.54	6.64
ATL	LGA	102	567.0	4.00	727	7	35000.	.52	9.16
ATL	LGA	432	567.0	4.00	D9S	7	35000.	.54	6.64
ATL	LGA	544	567.0	4.00	727	7	35000.	.52	9.16
ATL	LGA	572	567.0	4.00	72S	7	35000.	.53	10.00
ATL	MEM	560	217.0	12.00	DC9	7	32397.	1.57	19.72
ATL	MEM	652	217.0	12.00	D9S	7	32397.	1.60	20.89
ATL	MEM	980	217.0	12.00	727	7	33080.	1.55	28.70
ATL	MEM	992	217.0	12.00	72S	7	33080.	1.57	31.34
ATL	MIA	97	470.0	41.00	727	7	35000.	5.35	93.87
ATL	MIA	219	470.0	41.00	727	7	35000.	5.35	93.87
ATL	MIA	265	470.0	41.00	D9S	7	35000.	5.54	68.05
ATL	MIA	387	470.0	41.00	D9S	7	35000.	5.54	68.05
ATL	MIA	393	470.0	41.00	727	7	35000.	5.35	93.87
ATL	MIA	649	470.0	41.00	D9S	7	35000.	5.54	68.05
ATL	MSY	147	286.0	4.00	D9S	7	33480.	.54	6.82
ATL	MSY	149	286.0	4.00	727	7	35000.	.52	9.16
ATL	MSY	287	286.0	4.00	72S	7	35000.	.53	10.00
ATL	MSY	429	286.0	4.00	727	7	35000.	.52	9.16
ATL	MSY	793	286.0	4.00	DC9	7	33480.	.52	6.44
ATL	ORD	240	424.0	-2.00	DC9	7	34840.	-.26	-3.14
ATL	ORD	242	424.0	-2.00	72S	7	35000.	-.26	-5.00
ATL	ORD	244	424.0	-2.00	72S	5	35000.	-.26	-5.00
ATL	ORD	244	424.0	-2.00	727	2	35000.	-.26	-4.58
ATL	ORD	246	424.0	-2.00	DC9	7	34840.	-.26	-3.14
ATL	ORD	248	424.0	-2.00	DC9	7	34840.	-.26	-3.14
ATL	ORD	954	424.0	-2.00	L10	7	40400.	-.25	-9.07
ATL	PBI	141	389.0	-39.00	72S	7	35000.	-5.15	-97.51
ATL	PBI	245	389.0	-39.00	727	7	35000.	-5.09	-89.29
ATL	PBI	269	389.0	-39.00	DC9	7	34490.	-5.14	-61.56
ATL	PBI	329	389.0	-39.00	72S	7	35000.	-5.15	-97.51
ATL	PHL	114	506.0	13.00	D9S	7	35000.	1.76	21.58
ATL	PHL	120	506.0	13.00	727	7	35000.	1.70	29.76
ATL	PHL	122	506.0	13.00	D9S	7	35000.	1.76	21.58
ATL	PHL	124	506.0	13.00	D9S	7	35000.	1.76	21.58
ATL	PHL	140	506.0	13.00	L10	7	41000.	1.61	58.03
ATL	PHL	486	506.0	13.00	72S	7	35000.	1.72	32.50
ATL	PIT	320	376.0	5.00	727	7	35000.	.65	11.45
ATL	PIT	336	376.0	5.00	727	7	35000.	.65	11.45
ATL	PIT	988	376.0	5.00	72S	7	35000.	.66	12.50
ATL	SDF	252	190.0	-3.00	D9S	7	31667.	-.40	-5.33
ATL	SDF	254	190.0	-3.00	D9S	7	31667.	-.40	-5.33
ATL	SDF	256	190.0	-3.00	DC9	7	31667.	-.39	-5.02
ATL	SDF	462	190.0	-3.00	D9S	7	31667.	-.40	-5.33
ATL	SDF	712	190.0	-3.00	D9S	7	31667.	-.40	-5.33
ATL	STL	98	360.0	29.00	L10	7	38440.	3.59	133.76
ATL	STL	270	360.0	29.00	72S	7	35000.	3.83	72.51
ATL	STL	272	360.0	29.00	D9S	7	34200.	3.90	49.82
ATL	STL	274	360.0	29.00	D9S	7	34200.	3.90	49.82
ATL	STL	276	360.0	29.00	D9S	7	34200.	3.90	49.82
ATL	STL	452	360.0	29.00	727	7	35000.	3.78	66.40
ATL	TPA	289	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	299	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	365	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	485	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	629	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	727	277.0	11.00	72S	7	35000.	1.45	27.50
BAL	ATL	131	387.0	9.00	D9S	7	34470.	1.21	15.08
BAL	ATL	147	387.0	9.00	D9S	7	34470.	1.21	15.08
BAL	ATL	633	387.0	9.00	D9S	1	34470.	1.21	15.08
BAL	ATL	687	387.0	9.00	D9S	7	34470.	1.21	15.08
BAL	BOS	424	261.0	17.00	727	1	34840.	2.22	39.07
BAL	BOS	434	261.0	17.00	72S	6	34840.	2.24	42.66
BDL	DCA	593	187.0	23.00	D9S	7	31587.	3.06	40.69
BDL	DCA	889	187.0	23.00	D9S	7	31587.	3.06	40.69
BDL	MIA	181	-0.0	0.00	72S	7	12600.	0.00	0.00
BHM	ORD	224	434.0	30.00	D9S	7	34940.	4.05	49.84
BNA	ATL	299	100.0	4.00	72S	7	25800.	.51	12.19
BNA	ATL	399	100.0	4.00	D9S	7	27800.	.52	7.75
BNA	ATL	629	100.0	4.00	72S	7	25800.	.51	12.19
BNA	ATL	671	100.0	4.00	D9S	7	27800.	.52	7.75
BNA	ATL	695	100.0	4.00	72S	7	25800.	.51	12.19
BNA	ORD	258	258.0	6.00	727	7	34720.	.78	13.83
BNA	ORD	894	258.0	6.00	DC9	7	33180.	.79	9.71
BOS	ATL	129	748.0	5.00	72S	7	35000.	.66	12.50
BOS	ATL	145	748.0	5.00	727	7	35000.	.65	11.45
BOS	ATL	149	748.0	5.00	727	7	35000.	.65	11.45
BOS	ATL	533	748.0	5.00	D9S	7	35000.	.68	8.30
BOS	ATL	537	748.0	5.00	72S	6	35000.	.66	12.50
BOS	ATL	537	748.0	5.00	72S	1	35000.	.66	12.50
BOS	DCA	199	244.0	0.00	727	7	34160.	0.00	0.00
BOS	DCA	377	244.0	0.00	D9S	7	33040.	0.00	0.00
BOS	DCA	393	244.0	0.00	727	7	34160.	0.00	0.00
BOS	DCA	509	244.0	0.00	72S	7	34160.	0.00	0.00
BOS	DCA	869	244.0	0.00	D9S	7	33040.	0.00	0.00
BOS	JFK	491	76.0	17.00	72S	6	23880.	2.20	53.83
BOS	JFK	887	76.0	17.00	727	7	23880.	2.17	49.30
BOS	MIA	41	1030.0	0.00	72S	7	35000.	0.00	0.00
BOS	MIA	43	1030.0	0.00	727	7	35000.	0.00	0.00
BOS	MIA	47	1030.0	0.00	727	7	35000.	0.00	0.00
BOS	MIA	419	1030.0	0.00	727	7	35000.	0.00	0.00
BOS	PHL	809	195.0	35.00	L10	7	31933.	4.25	186.14
BUF	ATL	345	551.0	4.00	727	7	35000.	.52	9.16
BUF	ATL	625	551.0	4.00	72S	7	35000.	.53	10.00
BUF	ATL	961	551.0	4.00	L10	7	41000.	.49	17.85
BUF	PHL	125	191.0	38.00	727	7	31720.	4.89	92.77
CLT	JFK	354	390.0	25.00	D9S	7	34500.	3.37	41.87
CLT	ORD	212	428.0	10.00	D9S	7	34880.	1.35	16.63
CLT	ORD	214	428.0	10.00	D9S	7	34880.	1.35	16.63
CLT	ORD	218	428.0	10.00	D9S	7	34880.	1.35	16.63
CLT	ORD	226	428.0	10.00	D9S	7	34880.	1.35	16.63
CLT	PHL	374	312.0	12.00	D9S	7	33720.	1.61	20.37
CLT	PHL	540	312.0	12.00	727	7	35000.	1.57	27.47
CLT	PHL	596	312.0	12.00	727	7	35000.	1.57	27.47
CLT	PHL	604	312.0	12.00	72S	7	35000.	1.58	30.00
CLT	PIT	310	240.0	10.00	D9S	7	33000.	1.34	17.19
CLT	PIT	334	240.0	10.00	D9S	7	33000.	1.34	17.19

TABLE 3.39
EASTERN AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
CLT	PIT	348	240.0	10.00	D9S	7	33000.	1.34	17.19
CLT	PIT	476	240.0	10.00	72S	7	34000.	1.31	25.58
DCA	BOS	372	261.0	17.00	727	7	34840.	2.22	39.07
DCA	BOS	398	261.0	17.00	727	7	34840.	2.22	39.07
DCA	BOS	566	261.0	17.00	D9S	7	33210.	2.28	29.12
DCA	BOS	866	261.0	17.00	D9S	7	33210.	2.28	29.12
DCA	BOS	878	261.0	17.00	D9S	7	33210.	2.28	29.12
DCA	CLT	375	206.0	12.00	D9S	7	32093.	1.60	21.01
DCA	CLT	385	206.0	12.00	D9S	7	32093.	1.60	21.01
DCA	CLT	391	206.0	12.00	727	7	32520.	1.55	28.95
DCA	CLT	657	206.0	12.00	72S	7	32520.	1.57	31.62
DCA	JAX	199	465.0	7.00	727	7	35000.	.91	16.03
DCA	JAX	869	465.0	7.00	D9S	7	35000.	.95	11.62
DCA	LGA	1400	66.0	-3.00	D9S	5	26040.	-.39	-6.10
DCA	LGA	1410	66.0	-3.00	D9S	6	26040.	-.39	-6.10
DCA	LGA	1420	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1430	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1440	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1450	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1460	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1470	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1480	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1490	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1500	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1510	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1520	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1530	66.0	-3.00	D9S	6	26040.	-.39	-6.10
DCA	LGA	1540	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	MIA	175	718.0	5.00	D9S	7	35000.	.68	8.30
DCA	MIA	177	718.0	5.00	D9S	7	35000.	.68	8.30
DCA	MIA	195	718.0	5.00	727	7	35000.	.65	11.45
DCA	MIA	197	718.0	5.00	D9S	7	35000.	.68	8.30
DCA	MIA	473	718.0	5.00	D9S	7	35000.	.68	8.30
DCA	SDF	370	320.0	7.00	D9S	7	33800.	.94	11.87
DCA	SDF	509	320.0	7.00	72S	7	35000.	.92	17.50
DCA	STL	503	544.0	4.00	D9S	7	35000.	.54	6.64
DFW	ATL	114	563.0	4.00	D9S	7	35000.	.54	6.64
DFW	ATL	120	563.0	4.00	727	7	35000.	.52	9.16
DFW	ATL	286	563.0	4.00	DC9	7	35000.	.53	6.27
DFW	ATL	586	563.0	4.00	D9S	7	35000.	.54	6.64
DFW	ATL	666	563.0	4.00	727	7	35000.	.52	9.16
DTW	ORD	804	101.0	-4.00	727	1	25880.	-.50	-11.13
DTW	PIT	341	85.0	-1.00	727	7	24600.	-.13	-2.87
DTW	PIT	349	85.0	-1.00	D9S	7	26800.	-.13	-1.99
DTW	PIT	739	85.0	-1.00	727	7	24600.	-.13	-2.87
DTW	TPA	335	-0.0	0.00	D9S	7	18200.	0.00	0.00
DTW	TPA	463	-0.0	0.00	D9S	7	18200.	0.00	0.00
DTW	TPA	639	-0.0	0.00	D9S	7	18200.	0.00	0.00
EWR	ATL	105	569.0	4.00	72S	7	35000.	.53	10.00
EWR	ATL	135	569.0	4.00	DC9	7	35000.	.53	6.27
EWR	ATL	806	569.0	4.00	L10	7	41000.	.49	17.85
EWR	CLT	353	377.0	6.00	727	7	35000.	.78	13.74
EWR	CLT	359	377.0	6.00	D9S	7	34370.	.81	10.07
EWR	CLT	383	377.0	6.00	D9S	7	34370.	.81	10.07
EWR	FLL	407	868.0	7.00	72S	7	35000.	.92	17.50
EWR	FLL	745	868.0	7.00	727	7	35000.	.91	16.03
EWR	FLL	749	868.0	7.00	D9S	7	35000.	.95	11.62
EWR	FLL	759	868.0	7.00	727	7	35000.	.91	16.03
EWR	IAD	559	60.0	0.00	727	7	22200.	0.00	0.00
EWR	MIA	3	856.0	7.00	72S	7	35000.	.92	17.50
EWR	MIA	5	856.0	7.00	727	5	35000.	.91	16.03
EWR	MIA	5	856.0	7.00	D9S	2	35000.	.95	11.62
EWR	MIA	7	856.0	7.00	72S	7	35000.	.92	17.50
EWR	MIA	403	856.0	7.00	727	7	35000.	.91	16.03
EWR	TPA	165	811.0	7.00	L10	7	41000.	.87	31.25
EWR	TPA	423	811.0	7.00	D9S	7	35000.	.95	11.62
FLL	BOS	864	1029.0	9.00	727	7	35000.	1.17	20.61
FLL	BOS	880	1029.0	9.00	727	7	35000.	1.17	20.61
FLL	EWR	405	874.0	7.00	727	7	35000.	.91	16.03
FLL	EWR	742	874.0	7.00	72S	7	35000.	.92	17.50
FLL	EWR	746	874.0	7.00	D9S	7	35000.	.95	11.62
FLL	EWR	758	874.0	7.00	727	7	35000.	.91	16.03
FLL	JFK	412	864.0	5.00	L10	7	41000.	.62	22.32
FLL	JFK	750	864.0	5.00	727	7	35000.	.65	11.45
FLL	JFK	755	864.0	5.00	D9S	7	35000.	.68	8.30
FLL	ORD	458	957.0	8.00	727	7	35000.	1.04	18.32
FLL	ORD	790	957.0	8.00	727	7	35000.	1.04	18.32
FLL	ORD	796	957.0	8.00	727	7	35000.	1.04	18.32
FLL	PHL	408	853.0	7.00	727	7	35000.	.91	16.03
FLL	PHL	876	853.0	7.00	727	7	35000.	.91	16.03
FLL	TPA	180	90.0	-4.00	D9S	7	27000.	-.52	-7.92
FLL	TPA	342	90.0	-4.00	D9S	7	27000.	-.52	-7.92
FLL	TPA	500	90.0	-4.00	D9S	7	27000.	-.52	-7.92
GSO	LGA	362	304.0	11.00	D9S	7	33640.	1.48	18.70
GSO	LGA	366	304.0	11.00	D9S	7	33640.	1.48	18.70
GSO	LGA	580	304.0	11.00	D9S	7	33640.	1.48	18.70
GSO	ORD	206	434.0	0.00	DC9	7	34940.	0.00	0.00
GSO	ORD	363	434.0	0.00	D9S	7	34940.	0.00	0.00
IAD	EWR	558	99.0	-3.00	727	7	25720.	-.38	-8.39
IAD	JFK	554	100.0	-1.00	72S	7	25800.	-.13	-3.05
IAD	MSY	553	761.0	16.00	727	7	35000.	2.09	36.63
JAX	ATL	364	148.0	2.00	72S	7	29427.	.26	5.51
JAX	ATL	368	148.0	2.00	72S	7	29427.	.26	5.51
JAX	ATL	478	148.0	2.00	72S	7	29427.	.26	5.51
JAX	ATL	630	148.0	2.00	72S	5	29427.	.26	5.51
JAX	ATL	630	148.0	2.00	727	2	29427.	.25	5.05
JAX	ATL	676	148.0	2.00	D9S	7	30320.	.26	3.64
JAX	ATL	682	148.0	2.00	72S	7	29427.	.26	5.51
JAX	DCA	866	462.0	7.00	D9S	7	35000.	.95	11.62
JAX	DCA	878	462.0	7.00	D9S	7	35000.	.95	11.62
JAX	JFK	156	634.0	5.00	D9S	7	35000.	.68	8.30
JAX	MIA	397	203.0	0.00	727	7	32360.	0.00	0.00
JFK	ATL	103	572.0	18.00	72S	7	35000.	2.38	45.00
JFK	ATL	111	572.0	18.00	D9S	7	35000.	2.43	29.87
JFK	ATL	445	572.0	18.00	D9S	7	35000.	2.43	29.87
JFK	ATL	491	572.0	18.00	72S	6	35000.	2.38	45.00
JFK	BOS	494	106.0	50.00	727	7	26280.	6.30	137.45
JFK	FLL	477	888.0	7.00	L10	7	41000.	.87	31.25
JFK	FLL	743	888.0	7.00	72S	7	35000.	.92	17.50
JFK	FLL	755	888.0	7.00	D9S	7	35000.	.95	11.62
JFK	IAD	555	104.0	3.00	727	7	26120.	.38	8.29
JFK	MIA	9	874.0	0.00	L10	7	41000.	0.00	0.00
JFK	MIA	15	874.0	0.00	727	7	35000.	0.00	0.00
JFK	MIA	23	874.0	0.00	727	7	35000.	0.00	0.00
JFK	MIA	27	874.0	0.00	L10	7	41000.	0.00	0.00
JFK	MIA	401	874.0	0.00	L10	7	41000.	0.00	0.00
JFK	MIA	405	874.0	0.00	727	7	35000.	0.00	0.00
JFK	MSY	65	952.0	8.00	727	7	35000.	1.04	18.32
JFK	MSY	69	952.0	8.00	727	7	35000.	1.04	18.32
JFK	TPA	161	789.0	6.00	DC9	7	35000.	.79	9.40
JFK	TPA	167	789.0	6.00	727	7	35000.	.78	13.74
JFK	TPA	425	789.0	6.00	D9S	7	35000.	.81	9.96
LGA	ATL	87	560.0	4.00	727	6	35000.	.52	9.16
LGA	ATL	87	560.0	4.00	727	1	35000.	.52	9.16
LGA	ATL	101	560.0	4.00	727	7	35000.	.52	9.16
LGA	ATL	115	560.0	4.00	D9S	7	35000.	.54	6.64
LGA	ATL	543	560.0	4.00	72S	7	35000.	.53	10.00
LGA	ATL	547	560.0	4.00	D9S	7	35000.	.54	6.64
LGA	BHM	541	654.0	5.00	D9S	7	35000.	.68	8.30
LGA	CLT	351	387.0	16.00	727	7	35000.	2.09	36.63
LGA	CLT	357	387.0	16.00	72S	6	35000.	2.11	40.00
LGA	CLT	357	387.0	16.00	72S	1	35000.	2.11	40.00
LGA	CLT	397	387.0	16.00	727	7	35000.	2.09	36.63
LGA	CLT	545	387.0	16.00	D9S	7	34470.	2.16	26.81
LGA	DCA	1401	105.0	4.00	D9S	5	28200.	.52	7.67
LGA	DCA	1411	105.0	4.00	D9S	6	28200.	.52	7.67
LGA	DCA	1421	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1431	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1441	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1451	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1461	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1481	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1491	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1501	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1511	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1521	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1531	105.0	4.00	D9S	6	28200.	.52	7.67
LGA	DCA	1541	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	JAX	153	627.0	9.00	D9S	7	35000.	1.22	14.96
LGA	MIA	11	865.0	7.00	72S	5	35000.	.92	17.50
LGA	MIA	11	865.0	7.00	72S	1	35000.	.92	17.50
LGA	MIA	11	865.0	7.00	727	1	35000.	.91	16.03
LGA	MIA	17	865.0	7.00	L10	7	41000.	.87	31.25
LGA	MIA	21	865.0	7.00	727	6	35000.	.91	16.03
LGA	MIA	29	865.0	7.00	L10	7	41000.	.87	31.25
LGA	MIA	415	865.0	7.00	L10	7	41000.	.87	31.25
LGA	PBI	197	803.0	7.00	72S	7	35000.	.92	17.50
LGA	PBI	475	803.0	7.00	D9S	7	35000.	.95	11.62
MEM	ATL	861	201.0	-1.00	D9S	7	31960.	-.13	-1.76
MEM	ATL	865	201.0	-1.00	DC9	7	31960.	-.13	-1.66

TABLE 3.39
EASTERN AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
MEM	ATL	581	201.0	-1.00	72S	7	32253.	-.13	-2.65
MEM	ATL	933	201.0	-1.00	727	7	32253.	-.13	-2.42
MIA	ATL	252	453.0	23.00	D9S	7	35000.	3.11	39.17
MIA	ATL	452	453.0	23.00	727	7	35000.	3.00	52.66
MIA	ATL	564	453.0	23.00	72S	6	35000.	3.04	57.50
MIA	ATL	564	453.0	23.00	72S	1	35000.	3.04	57.50
MIA	ATL	602	453.0	23.00	727	7	35000.	3.00	52.66
MIA	ATL	616	453.0	23.00	72S	7	35000.	3.04	57.50
MIA	ATL	678	453.0	23.00	727	7	35000.	3.00	52.66
MIA	BAL	172	762.0	6.00	72S	7	35000.	.79	15.00
MIA	BDL	192	977.0	9.00	72S	7	35000.	1.19	22.50
MIA	BOS	42	1081.0	9.00	727	7	35000.	1.17	20.61
MIA	BOS	46	1081.0	9.00	72S	7	35000.	1.19	22.50
MIA	BOS	418	1081.0	9.00	727	7	35000.	1.17	20.61
MIA	CMH	302	814.0	7.00	727	7	35000.	.91	16.03
MIA	DCA	159	747.0	6.00	727	5	35000.	.78	13.74
MIA	DCA	158	747.0	6.00	D9S	2	35000.	.81	9.96
MIA	DCA	176	747.0	6.00	727	7	35000.	.78	13.74
MIA	DCA	190	747.0	6.00	D9S	7	35000.	.81	9.96
MIA	DCA	192	747.0	6.00	72S	7	35000.	.79	15.00
MIA	DCA	198	747.0	6.00	D9S	7	35000.	.81	9.96
MIA	DFW	976	326.0	11.00	727	7	35000.	1.43	25.19
MIA	DTW	422	924.0	8.00	727	7	35000.	1.04	18.32
MIA	DTW	952	924.0	8.00	L10	7	41000.	.99	35.71
MIA	EWR	4	889.0	7.00	72S	7	35000.	.92	17.50
MIA	EWR	6	889.0	7.00	D9S	7	35000.	.95	11.62
MIA	EWR	8	889.0	7.00	72S	7	35000.	.92	17.50
MIA	EWR	402	889.0	7.00	72S	7	35000.	.92	17.50
MIA	JFK	14	881.0	8.00	727	7	35000.	1.04	18.32
MIA	JFK	18	881.0	8.00	727	7	35000.	1.04	18.32
MIA	JFK	22	881.0	8.00	D9S	7	35000.	1.09	13.28
MIA	JFK	26	881.0	8.00	L10	7	41000.	.99	35.71
MIA	JFK	400	881.0	8.00	L10	7	41000.	.99	35.71
MIA	LGA	16	892.0	7.00	L10	7	41000.	.87	31.25
MIA	LGA	20	892.0	7.00	72S	6	35000.	.92	17.50
MIA	LGA	20	892.0	7.00	727	1	35000.	.91	16.03
MIA	LGA	24	892.0	7.00	727	7	35000.	.91	16.03
MIA	LGA	28	892.0	7.00	727	6	35000.	.91	16.03
MIA	LGA	414	892.0	7.00	L10	7	41000.	.87	31.25
MIA	LGA	892	892.0	7.00	L10	7	41000.	.87	31.25
MIA	MSY	524	509.0	2.00	D9S	7	35000.	.27	3.32
MIA	MSY	907	509.0	2.00	72S	7	35000.	.26	5.00
MIA	ORD	72	959.0	8.00	727	7	35000.	1.04	18.32
MIA	ORD	78	959.0	8.00	727	7	35000.	1.04	18.32
MIA	ORD	430	959.0	8.00	727	7	35000.	1.04	18.32
MIA	PHL	34	820.0	7.00	727	7	35000.	.91	16.03
MIA	PHL	36	820.0	7.00	727	7	35000.	.91	16.03
MIA	PHL	419	820.0	7.00	72S	7	35000.	.92	17.50
MIA	PHL	956	820.0	7.00	L10	7	41000.	.87	31.25
MIA	PIT	300	811.0	6.00	72S	7	35000.	.79	15.00
MIA	PIT	482	811.0	6.00	D9S	7	35000.	.81	9.96
MIA	STL	222	861.0	7.00	D9S	7	35000.	.95	11.62
MIA	STL	690	861.0	7.00	D9S	7	35000.	.95	11.62
MIA	TPA	614	90.0	-4.00	D9S	7	27000.	-.52	-7.92
MIA	TPA	672	90.0	-4.00	D9S	7	27000.	-.52	-7.92
MKE	ATL	787	518.0	25.00	D9S	7	35000.	3.38	41.49
MKE	ATL	789	518.0	25.00	727	7	35000.	3.26	57.24
MSY	ATL	103	288.0	0.00	727	7	35000.	0.00	0.00
MSY	ATL	428	288.0	0.00	727	7	35000.	0.00	0.00
MSY	ATL	556	288.0	0.00	D9S	7	33480.	0.00	0.00
MSY	ATL	534	288.0	0.00	72S	7	35000.	0.00	0.00
MSY	ATL	789	288.0	0.00	DC9	7	33480.	0.00	0.00
MSY	JFK	66	961.0	8.00	727	7	35000.	1.04	18.32
MSY	MIA	521	505.0	7.00	727	7	35000.	.91	16.03
MSY	MIA	906	505.0	7.00	727	7	35000.	.91	16.03
OKC	DEN	980	365.0	20.00	727	7	35000.	2.61	45.79
ORD	ATL	241	435.0	17.00	D9S	7	34950.	2.30	28.24
ORD	ATL	234	435.0	17.00	D9S	7	34950.	2.30	28.24
ORD	ATL	245	435.0	17.00	727	7	35000.	2.22	38.92
ORD	ATL	247	435.0	17.00	DC9	7	34950.	2.25	26.65
ORD	ATL	249	435.0	17.00	D9S	7	34950.	2.30	28.24
ORD	ATL	957	435.0	17.00	L10	7	40840.	2.10	76.26
ORD	BHM	225	409.0	3.00	DC9	7	34690.	.40	4.73
ORD	BNA	257	254.0	1.00	727	7	34560.	.13	2.31
ORD	BNA	891	254.0	1.00	DC9	7	33140.	.13	1.62
ORD	CLT	215	443.0	20.00	D9S	7	35000.	2.70	33.19
ORD	CLT	217	443.0	20.00	D9S	7	35000.	2.70	33.19
ORD	CLT	227	443.0	20.00	D9S	7	35000.	2.70	33.19
ORD	DTW	803	163.0	1.00	727	1	26040.	.13	2.77
ORD	FLL	469	950.0	8.00	D9S	7	35000.	1.08	13.28
ORD	FLL	791	950.0	8.00	727	7	35000.	1.04	18.32
ORD	FLL	795	960.0	8.00	727	7	35000.	1.04	18.32
ORD	GSO	207	-0.0	0.00	DC9	7	18200.	0.00	0.00
ORD	GSO	209	-0.0	0.00	DC9	7	18200.	0.00	0.00
ORD	MIA	75	953.0	8.00	727	7	35000.	1.04	18.32
ORD	MIA	79	953.0	8.00	72S	7	35000.	1.06	20.00
ORD	MIA	433	953.0	8.00	72S	5	35000.	1.06	20.00
ORD	MIA	433	953.0	8.00	727	2	35000.	1.04	18.32
ORD	MIA	993	953.0	8.00	727	7	35000.	1.04	18.32
ORD	RDU	203	507.0	48.00	D9S	7	35000.	6.49	79.67
ORD	RDU	205	507.0	48.00	DC9	7	35000.	6.34	75.20
ORD	TPA	237	804.0	6.00	727	7	35000.	.78	13.74
ORD	TPA	259	804.0	6.00	727	7	35000.	.78	13.74
ORD	TPA	437	804.0	6.00	D9S	7	35000.	.61	9.96
PBI	ATL	106	391.0	0.00	727	7	35000.	0.00	0.00
PBI	ATL	142	391.0	0.00	72S	7	35000.	0.00	0.00
PBI	ATL	242	391.0	0.00	72S	7	35000.	0.00	0.00
PBI	ATL	632	391.0	0.00	72S	7	35000.	0.00	0.00
PBI	JFK	194	877.0	8.00	72S	7	35000.	1.06	20.00
PBI	JFK	196	877.0	8.00	L10	7	41000.	.99	35.71
PBI	JFK	440	877.0	8.00	727	7	35000.	1.04	18.32
PBI	LGA	284	823.0	7.00	D9S	7	35000.	.95	11.62
PHL	ATL	121	500.0	9.00	727	7	35000.	1.17	20.61
PHL	ATL	123	500.0	9.00	727	7	35000.	1.17	20.61
PHL	ATL	125	500.0	9.00	727	7	35000.	1.17	20.61
PHL	ATL	127	500.0	9.00	727	7	35000.	1.17	20.61
PHL	ATL	449	500.0	9.00	L10	7	41000.	1.11	49.17
PHL	ATL	561	500.0	9.00	72S	7	35000.	1.19	22.50
PHL	BOS	556	203.0	43.00	727	7	32627.	5.55	103.53
PHL	BUF	646	210.0	53.00	727	7	32733.	6.85	127.47
PHL	CLT	373	329.0	21.00	D9S	7	33890.	2.82	35.55
PHL	CLT	379	329.0	21.00	D9S	7	33890.	2.82	35.55
PHL	CLT	579	329.0	21.00	D9S	7	33890.	2.82	35.55
PHL	CLT	603	329.0	21.00	D9S	7	33890.	2.82	35.55
PHL	MIA	35	816.0	7.00	L10	7	41000.	.87	31.25
PHL	MIA	37	816.0	7.00	727	7	35000.	.91	16.03
PHL	MIA	39	816.0	7.00	727	7	35000.	.91	16.03
PHL	MIA	411	816.0	7.00	727	7	35000.	.91	16.03
PHL	MSY	575	-0.0	0.00	727	7	12600.	0.00	0.00
PIT	ATL	327	388.0	19.00	D9S	7	34480.	2.56	31.83
PIT	ATL	329	388.0	19.00	72S	7	35000.	2.51	47.50
PIT	ATL	989	388.0	19.00	72S	7	35000.	2.51	47.50
PIT	CLT	311	235.0	3.00	72S	7	33800.	.39	7.71
PIT	CLT	317	235.0	3.00	D9S	7	32867.	.40	5.17
PIT	CLT	341	235.0	3.00	727	7	33800.	.39	7.05
PIT	CLT	349	235.0	3.00	D9S	7	32867.	.40	5.17
PIT	FLL	309	810.0	17.00	727	7	35000.	2.22	38.92
PIT	MIA	303	809.0	6.00	72S	7	35000.	.79	15.00
PIT	MIA	483	809.0	6.00	727	5	35000.	.78	13.74
PIT	MIA	483	809.0	6.00	D9S	2	35000.	.81	9.96
RDU	ATL	219	223.0	2.00	727	7	33320.	.26	4.76
RDU	ATL	361	223.0	2.00	72S	6	33320.	.26	5.19
RDU	ATL	361	223.0	2.00	72S	1	33320.	.26	5.19
RDU	ATL	393	223.0	2.00	727	7	33320.	.26	4.76
RDU	ATL	549	223.0	2.00	72S	7	33320.	.26	5.19
RDU	ATL	585	223.0	2.00	72S	5	33320.	.26	5.19
RDU	ATL	585	223.0	2.00	727	2	33320.	.26	4.76
RDU	ORD	204	489.0	0.00	D9S	7	35000.	0.00	0.00
RDU	ORD	208	489.0	0.00	D9S	7	35000.	0.00	0.00
RIC	LGA	562	146.0	0.00	727	7	29320.	0.00	0.00
RIC	LGA	898	146.0	0.00	D9S	7	30240.	0.00	0.00
SDF	ATL	261	203.0	12.00	DC9	7	32013.	1.56	19.87
SDF	ATL	265	203.0	12.00	D9S	7	32013.	1.60	21.05
SDF	ATL	269	203.0	12.00	DC9	7	32013.	1.56	19.87
SDF	ATL	435	203.0	12.00	D9S	7	32013.	1.60	21.05
SDF	ATL	653	203.0	12.00	D9S	7	32013.	1.60	21.05
SDF	DCA	254	321.0	12.00	D9S	7	33810.	1.61	20.34
SDF	DCA	508	321.0	12.00	72S	7	35000.	1.58	30.00
STL	ATL	97	334.0	1.00	727	7	35000.	.13	2.29
STL	ATL	99	334.0	1.00	L10	7	37608.	.12	4.93
STL	ATL	271	334.0	1.00	D9S	7	33940.	.13	1.69
STL	ATL	273	334.0	1.00	D9S	7	33940.	.13	1.69
STL	ATL	289	334.0	1.00	72S	7	35000.	.13	2.50
STL	ATL	699	334.0	1.00	D9S	7	33940.	.13	1.69
STL	DCA	510	532.0	4.00	D9S	7	35000.	.54	6.64
TPA	ATL	280	301.0	35.00	D9S	7	33610.	4.70	59.54
TPA	ATL	476	301.0	35.00	72S	7	35000.	4.62	87.51
TPA	ATL	484	301.0	35.00	727	7	35000.	4.57	80.13
TPA	ATL	546	301.0	35.00	72S	7	35000.	4.62	87.51
TPA	ATL	572	301.0	35.00	72S	7	35000.	4.62	87.51
TPA	ATL	624	301.0	35.00	72S	7	35000.	4.62	87.51

TABLE 3.39
EASTERN AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
TPA	ATL	476	301.0	35.00	72S	7	35000.	4.62	87.51
TPA	ATL	488	301.0	35.00	727	7	35000.	4.57	80.13
TPA	ATL	546	301.0	35.00	72S	7	35000.	4.62	87.51
TPA	ATL	572	301.0	35.00	72S	7	35000.	4.62	87.51
TPA	ATL	624	301.0	35.00	72S	7	35000.	4.62	87.51
TPA	CLE	316	728.0	5.00	D9S	7	35000.	.68	8.30
TPA	DTW	340	797.0	7.00	D9S	7	35000.	.95	11.62
TPA	DTW	344	797.0	7.00	D9S	7	35000.	.95	11.62
TPA	DTW	464	797.0	7.00	D9S	7	35000.	.95	11.62
TPA	EWR	168	816.0	6.00	L10	7	41000.	.74	26.78
TPA	FLL	189	103.0	18.00	72S	7	26040.	2.29	54.43
TPA	FLL	223	103.0	18.00	D9S	7	28040.	2.36	34.67
TPA	FLL	339	103.0	18.00	D9S	7	28040.	2.36	34.67
TPA	FLL	485	103.0	18.00	72S	7	26040.	2.29	54.43
TPA	FLL	529	103.0	18.00	DC9	7	28040.	2.31	32.73
TPA	JFK	160	928.0	8.00	727	7	35000.	1.04	18.32
TPA	JFK	162	928.0	8.00	727	7	35000.	1.04	18.32
TPA	JFK	426	928.0	8.00	727	7	35000.	1.04	18.32
TPA	MIA	127	103.0	18.00	727	7	26040.	2.27	49.84
TPA	MIA	437	103.0	18.00	D9S	7	28040.	2.36	34.67
TPA	MIA	645	103.0	18.00	72S	6	26040.	2.29	54.43
TPA	MIA	645	103.0	18.00	72S	1	26040.	2.29	54.43
TPA	ORD	230	793.0	6.00	727	7	35000.	.78	13.74
TPA	ORD	262	793.0	6.00	DC9	7	35000.	.79	9.40
TPA	ORD	466	793.0	6.00	727	7	35000.	.78	13.74

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE

RNAV benefits were derived from the airline schedule files described earlier and the benefits results for the fifty-eight (58) airports. Potential benefits at other airports served by an airline were not considered. Benefit determination at any given airport proceeded as follows: For each flight, the origin airport was examined to determine if it is one of the nine (9) primary airports. If so, the benefit data for the aircraft type most nearly like the actual aircraft were taken from Table 3.3 and multiplied by the fuel and time conversion factors for that aircraft type (as discussed earlier). Note that only origin airports need be examined; total benefits are then twice the per operation benefits, accounting for the arrival and departure at that airport.

If the origin airport is not among the nine (9) primaries, it was examined to determine if it is one of the other forty-nine (49). If not, the next flight is selected and the procedure repeated. If so, then the proper extrapolation equation was selected for the aircraft type and the results were multiplied by the aircraft conversion factors, as before, to get fuel and time benefits for that flight.

<u>3D RNAV Benefits</u>

The benefits due to 3D RNAV (VNAV) in descent operations are discussed in Section 3.1.2. In that section it was shown that VNAV capability may be used to conduct descents more advantageously in terms of fuel and time usage, regardless of where the descent is conducted. Therefore, if VNAV descent procedures are adhered to by an airline throughout its route structure, this benefit is available for each descent conducted. Therefore, airline VNAV benefits computation was a rather straightforward process. The annual descent operations conducted by each type of aircraft were counted, and the totals were multiplied by the benefit values shown in Tables 3.8, as modified by the appropriate individual aircraft type conversion factors, as done before, to get aggregate VNAV benefits for each aircraft type in an airline's inventory.

3.6.4 4D RNAV Benefits

The benefits due to 4D RNAV in terminal arrival operations are discussed in Section 3.4.3. In that section, Table 3.29 was created which shows the potential per operation benefits available to operators at each of the twenty-five (25) highest delay airports, given that 4D operations are in extensive use. These benefits are in terms of delay reduction per operation, and are independent of aircraft type. Only time, not fuel, savings were calculated; fuel savings may be derived from time savings for a given aircraft type from low altitude cruise performance data. The cruise condition selected as being appropriate in representing the condition where such a delay reduction would be experienced was a holding pattern at 15,000 ft. Fuel consumption (gpm) rates were determined for the five (5) primary aircraft types from the performance manuals at that condition, and so fuel benefits could also be calculated.

In order to assess 4D RNAV benefits for a given airline, each operation was examined to determine if the destination airport was among the twenty-five (25) listed in Table 3.29. If not, no contribution to total 4D benefit was made. If so, the time savings per operation was multiplied by the fuel consumption rate, as modified by the appropriate aircraft type conversion factor, as done before, to determine the contribution to aggregate 4D RNAV benefits for that aircraft type.

3.6.5 Data Aggregation and Extrapolation

It was desired to be able to express RNAV benefits individually for each airline and for each aircraft type within each airline on a per aircraft basis. The per aircraft mode of expression is extremely important since it shows the degree of payoff to be expected for each individual RNAV installation. In order to make that computation, fleet composition data was obtained from each airline. It is further significant to show RNAV benefits individually for each aircraft type since the particular types of operations and routes flown by individual types of aircraft for individual airlines have a very strong influence upon the magnitude of the resulting benefits due to enroute and terminal 2D/3D RNAV and 4D RNAV.

In order to express benefits by airline and by individual aircraft type, the analysis programs were designed to accumulate total time and fuel benefits separately for each individual aircraft type and each airline. Furthermore, in the case of the 2D RNAV benefits evaluation, total route miles flown were aggregated, as were total route miles flown on remaining routes for which benefits data was not directly available. As discussed earlier, the percent of operations conducted on the NAFEC structure by each aircraft could then be computed. This was very useful for extrapolating total benefits presuming that a comprehensive RNAV structure were implemented. Since basic RNAV benefits are sensitive to the particular routes flown, it follows that the operations flown by a particular aircraft type on certain routes within the NAFEC structure are more representative of total RNAV benefits available to that aircraft type than the entire NAFEC structure would be as a whole. Therefore, extrapolation on an individual aircraft type basis is preferable.

In the case of the VNAV benefits analysis, no extrapolation is necessary since the VNAV benefit for each arrival has been included. The 4D RNAV benefits analysis concerned only operations at the twenty-five (25) airports with highest total delay. However, it is not appropriate to extrapolate these results to the remainder of operations for two reasons. First, the benefit to be realized diminishes rapidly as operations rate and total delay decreases at the smaller airports making extrapolation tenuous. Second, and more important, the 4D benefit can only be realized at airports employing a sophisticated form of Metering and Spacing automation. The number of airports with such services available will most certainly be limited to the higher delay airports. Likewise, 2D terminal area benefits were not extrapolated beyond the fifty-eight (58) airports.

Table 3.40 lists the total annual flight miles, based on the 1 February 1976 OAG, by aircraft type for each airline studied as well as the percent of those flight miles which would occur on the NAFEC 429 airport pair high altitude structure. The flight hour cost range for each aircraft, also listed in Table 3.40 was computed as follows: The high end of the range was based on 1973 Direct Operating Cost (DOC) minus fuel [37], inflated to 1975 dollars at 5.5% per year, plus fuel at $.30 per gallon. The low end of the range was based on 1973 DOC minus fuel, depreciation, and rentals. This figure was then arbitrarily reduced by 20% (to allow for further variation of flight time sensitive DOC among individual airlines) prior to inflating to 1975 dollars. Fuel at $.18 per gallon (representing lowest current prices) was then added.

The projected annual total and per aircraft benefits for EAL are given in Table 3.41 for 2D and 3D and in 3.42 for 4D. The projected benefits for the other airlines studied are given in Appendix G.

Table 3.40
Airline Flight Hour Cost Range

UAL

AIRCRAFT	TOTAL ANNUAL ENROUTE FLIGHT MILES	% OF ANNUAL ENROUTE FLIGHT MILES ON NAFEC STRUCTURE	FLIGHT HOUR COST RANGE (LESS FUEL)	
			HIGH	LOW
727	86,061,307	45%	$ 612	$ 356
727-222	20,487,791	61%	647	353
737-222	18,606,697	58%	565	346
DC-10	33,633,192	84%	1297	602
DC 8	41,249,912	58%	768	396
DC 8-61/62	30,032,832	81%	877	374
747	6,604,780	100%	1433	660

TWA

AIRCRAFT	TOTAL ANNUAL ENROUTE FLIGHT MILES	% OF ANNUAL ENROUTE FLIGHT MILES ON NAFEC STRUCTURE	FLIGHT HOUR COST RANGE (LESS FUEL)	
			HIGH	LOW
L1011	21,421,754	94%	$1373	$542
727	27,869,383	65%	636	373
727-200	33,363,355	56%	642	310
DC-9	8,708,373	51%	644	363
707	63,241,652	72%	744	392
747	1,533,168	100%	1907	563

NAL

AIRCRAFT	TOTAL ANNUAL ENROUTE FLIGHT MILES	% OF ANNUAL ENROUTE FLIGHT MILES ON NAFEC STRUCTURE	FLIGHT HOUR COST RANGE (LESS FUEL)	
			HIGH	LOW
727	7,651,302	64%	$ 574	$ 334
727-200	18,527,601	39%	610	363
DC-10	20,929,614	63%	1038	516

Table 3.40
(Cont'd.)

EAL

AIRCRAFT	TOTAL ANNUAL ENROUTE FLIGHT MILES	% OF ANNUAL ENROUTE FLIGHT MILES ON NAFEC STRUCTURE	FLIGHT HOUR COST RANGE (LESS FUEL) HIGH	LOW
L-1011	13,911,792	58%	$1614	$ 499
727	64,878,577	49%	668	414
727-200	32,388,897	49%	597	339
DC-9-14	7,409,371	44%	466	250
DC-9-31	51,856,801	44%	500	301

DAL

AIRCRAFT	TOTAL ANNUAL ENROUTE FLIGHT MILES	% OF ANNUAL ENROUTE FLIGHT MILES ON NAFEC STRUCTURE	FLIGHT HOUR COST RANGE (LESS FUEL) HIGH	LOW
DC 8-51	7,686,915	67%	$ 629	$404
747	21,455,556	27%	1907	563
L1011	16,902,233	81%	1677	523
DC 8-61	10,030,994	73%	812	436
727-95/232/295	70,020,915	57%	635	326
DC-9	34,291,234	43%	438	230

AAL

AIRCRAFT	TOTAL ANNUAL ENROUTE FLIGHT MILES	% OF ANNUAL ENROUTE FLIGHT MILES ON NAFEC STRUCTURE	FLIGHT HOUR COST RANGE (LESS FUEL) HIGH	LOW
707-123/323	62,486,119	70%	$ 905	$ 450
727	86,379,812	62%	624	338
DC-10	24,227,667	94%	1225	590
747	1,482,208	100%	2710	1395

Table 3.41

RNAV Benefits over VOR for 2/1/76 Schedule and Route Structure

EAL

		ANNUAL					PER AIRCRAFT			
Aircraft Type	Benefit	Fuel (gal)	Time (min)	$ Range Low	$ Range High	# of Aircraft	Fuel (gal)	Time (min)	$ Range Low	$ Range High
L10	2D Enroute	691K	18K	273K	687K	30	23.1K	607	9,202	23,248
	2D TMA	1498K	41K	610K	1552K		49.9K	1382	20,475	52,146
	3D TMA	227K	6K	91K	230K		7.6K	198	3,015	7,606
	Total	2416K	65K	974K	2569K		80.6K	2187	32,692	83,000
727	2D Enroute	2.20M	122K	1.24M	2.02M	75	29.4K	1631	16,544	26,975
	2D TMA	3.10M	162K	1.68M	2.73M		41.3K	2161	22,344	36,449
	3D TMA	.89M	41K	.44M	.72M		11.9K	544	5,896	9,627
	Total	6.19M	325K	3.36M	5.47M		82.6K	4336	44,784	73,051
72S	2D Enroute	1.39M	70K	.647M	1.114M	39	35.5K	1800	16,566	28,570
	2D TMA	2.36M	120K	1.103M	1.902M		60.5K	3066	28,213	48,657
	3D TMA	.67M	28K	.279M	.480M		17.2K	729	7,215	12,414
	Total	4.42M	218K	2.029M	3.496M		113.2K	5595	51,994	89,641
DC9	2D Enroute	147K	12K	77K	138K	8	18.3K	1471	9,427	16,922
	2D TMA	322K	25K	162K	291K		40.2K	3169	20,440	36,672
	3D TMA	179K	11K	78K	139K		22.4K	1429	9,986	17,819
	Total	648K	48K	317K	568K		80.9K	6069	39,853	71,413
D9S	2D Enroute	1.97M	157K	1.15M	1.90M	73	27.1K	2157	15,692	26,094
	2D TMA	3.37M	229K	1.76M	2.92M		46.2K	3136	24,048	39,993
	3D TMA	1.44M	89K	.71M	1.17M		19.7K	1213	9,631	16,018
	Total	6.78M	475K	3.62M	5.99M		92.9K	6506	49,371	82,105

Table 3.42

EAL

4D RNAV PROJECTED BENEFITS

Aircraft Type	ANNUAL					PER AIRCRAFT				
	Fuel (gal)	Time (min.)	$ Range		# of Aircraft	Fuel (gal)	Time (min.)	$ Range	
			Low	High				Low	High
L10	1163K	40K	542K	1425K	30	38.8K	1333	18,067	47,497
727	2825K	190K	1820K	2963K	75	37.7K	2533	24,260	39,504
72S	2217K	136K	1167K	2018K	39	56.8K	3487	29,935	51,751
DC9	441K	44K	264K	476K	8	55.8K	5500	32,952	59,442
D9S	2571K	241K	1672K	2780K	73	35.2K	3301	22,901	38.077

4.0 SYSTEM IMPACT ANALYSIS

4.1 SLANT RANGE EFFECTS

The problem of the slant range error effect on DME measurement accuracy has long been recognized. Provisions for additional protected airspace requirements near VORTACs have been made in the airspace handbook (Handbook 7110.18[38], based upon earlier analyses. The RNAV Task Force has recognized the slant range problem as both an airspace problem and as an equipment requirements and cost problem. It is therefore the intent of this section to investigate the slant range error problem in order to determine the actual impact of slant range error on aircraft track deviations and cockpit procedures in the lower altitudes (below 18,000 ft). It is furthermore the purpose of this section to investigate the airspace allocation criteria and equipment requirements criteria stated in Handbook 7110.18 and the Task Force Report [1], and to develop new criteria based upon the results of these new analyses and flight tests. Finally, the low altitude, high altitude and terminal area environments are evaluated as to the impact of slant range error and these newly developed criteria on the flexibility of the route designer in the placement of routes, and the operational flexibility of the controller in utilizing RNAV maneuvers.

The major task of this analysis is to examine the influence of slant range error on deviations from desired track and on cockpit procedures. The determination of airborne equipment requirements and/or effects on airspace design procedures are affected by slant range induced track deviations and pilot reactions. One potential solution to the slant range error problem is the requirement for slant range correction for all users or for admission to certain airspace. This is a step to be taken only after careful deliberation since the impact on low-cost RNAV systems is significant, due to the fact that increased capabilities of both the altimetry and RNAV computational systems are required. Alternatively, if the slant range effects on airspace requirements or cockpit operational problems are severe, slant range correction or restrictive route design procedures which could impact route efficiency may be required. It was therefore the intent of this analysis to concentrate the study of the slant range error problem where it is least severe, where encoding altimeters are not necessarily required (below 12,500 ft.), and where the overwhelming majority of lower capability general aviation users operate: the low altitude and terminal area airspace. Using the data and techniques so developed, operations in the intermediate (12,5000 to 18,000 ft.) airspace and high altitude airspace have also been evaluated.

4.1.1 <u>Methodology</u>

The slant range error effect has been the subject of analysis for quite some time. The magnitude of the guidance error is easily determined under any specified conditions. However, the resulting effect upon actual deviations from intended track is very difficult to assess, although it is widely accepted to be significant for aircraft at high altitudes. Likewise, the degree to which the guidance fluctuations disturb the flight crew is not readily apparent. Very little flight test work has been performed in this area. As a direct

result of this, a specific test program dedicated to the slant range error effect in the terminal area environment was conceived and carried out, and the results were used to calibrate a simulation algorithm so that flight regimes other than the ones tested could be analyzed.

The first step in the procedure was to plan and conduct a dedicated slant range error flight test program. The flight test plan is presented in Appendix E. Briefly, a twenty mile long track was specified with the VORTAC at the middle. Four combinations of altitude and nominal tangent point distance were selected, with two pilots flying each combination twice plus one additional flight, for a total of seventeen flights. The data recording and recovery techniques used were identical to earlier test programs at Denver and Miami [8], except that DME range, TO/FROM flag and CDI valid flag data were also recorded. Data reduction and computer processing procedures were also similar to those used for the earlier test programs, except that an additional error analysis program was developed to process the DME data and isolate the slant range error components, and compute statistical values. Diagrams showing actual aircraft track and RNAV indicated track were created for each flight, and are included in Appendix E.

The resulting flight test data was analyzed in an attempt to determine the effect of slant range error as it disturbs achieved track as compared to hypothetical identical flights with no error. This effort was complicated considerably by the presence of other errors in the navigation system and VORTAC which typify such RNAV operations. Pilot and observer comments and the data were reviewed to assess the operational significance of the slant range effect, particularly in comparison to other operational problems including navigation errors and signal dropouts.

In order to further refine the analysis of the flight test data and to be able to determine the effect on other types of aircraft operating at different speeds, a dynamic computer simulation program was developed. This program was similar to, and used the same aircraft/pilot control system as, the simulation reported in Reference 39. The specific control system sensitivities and parameters were adjusted in order to match closely the slant range error induced effect apparent in the flight test data. The flight test aircraft model was then simulated over a wide range of altitudes and tangent point distances. More importantly, a very slow aircraft representative of the class of aircraft most seriously affected by the slant range error was simulated over a broad range of conditions. A faster, less maneuverable aircraft was also modeled in order to confirm that the effect is less significant in that case. The results of these simulation studies have been expressed in two ways which are critical to the understanding of the slant range error effect on airspace requirements. First, the additional airspace required to assure that 95% of the aircraft remain within boundaries is discussed. Alternatively, plots are shown which depict the decrease in level of confidence of remaining within a fixed route width as a function of nominal tangent point distance.

4.1.2 Terminal and Low Altitude Analysis

It is obvious from an examination of the aircraft track plots, a typical example of which appears as Figure 4.1, that the slant range effect is well hidden amongst all of the other errors and disturbances affecting each flight. While this made analysis rather difficult, it is perhaps an early indicator of the relative magnitude of the slant range effect under 12,500 ft. The most obvious errors are an angular bias in the RNAV/VORTAC system, and a scallop effect. The scalloping was reported by the flight crew, particularly on the west side of the station when flying west. The slant range effect experienced by an aircraft is dependent wholly upon the actual track it is making good, not the intended or nominal track. Also, since the nominal track is deviated from, the slant range error effect on track deviation must be measured with respect to the track which probably would have been achieved had there been no slant range error, rather than the nominal track. In the case of simulation there is no problem since no other errors exist to disturb the track. Flight test data is quite another story, however. In order to attempt to discern the probable track without slant range error, the trend of the aircraft position at intervals along the inbound (to the VORTAC) portion of the track was determined by a least square curve fit to a straight line. Two measurements were then made with respect to this straight line: the actual tangent point distance of the achieved track, and the maximum deviation of the aircraft from the line immediately following VORTAC passage. The first measure, along with altitude, is the basic parameter affecting slant range error. The second was an attempt to quantify the track deviation due to slant range error. If no other errors were present, these two measures should be related in some consistent manner. However, certain flaws are obvious. First, the curve fit is not necessarily an accurate representation of the actual situation and, second, the deviation value measured includes the effects of other navigation errors and winds. The results of these tests are summarized in Table 4.1. The table lists, for each flight, the subject pilot, direction of flight, altitude, tangent distance to the nominal track, the angle corresponding to that distance, the tangent distance to the curve-fit track and the corresponding angle, the mean and standard deviation of system cross track error and the maximum deviation ("track bulge") attributed to slant range error. Note that in two cases (flights 6 and 8) the curve fit could not be reliably applied. These maximum deviation results, versus tangent point distance, are plotted in Figure 4.2. The data is noisy and this is highlighted by the fact that the 8000 ft points show in general a greater deviation than the 12000 ft points, which is contrary to expectations. The simulation, as discussed below, was subsequently used to remove much of this noise from the flight test data, revealing a much more reasonable result.

4.1.2.1 Simulated Aircraft Control System

The basic control system equations are documented in Reference 39. The heart of the system is a third order autopilot/aircraft model which uses cross track deviation, heading and command heading inputs. The parameters of significance include the cross track deviation gain, the maximum aircraft

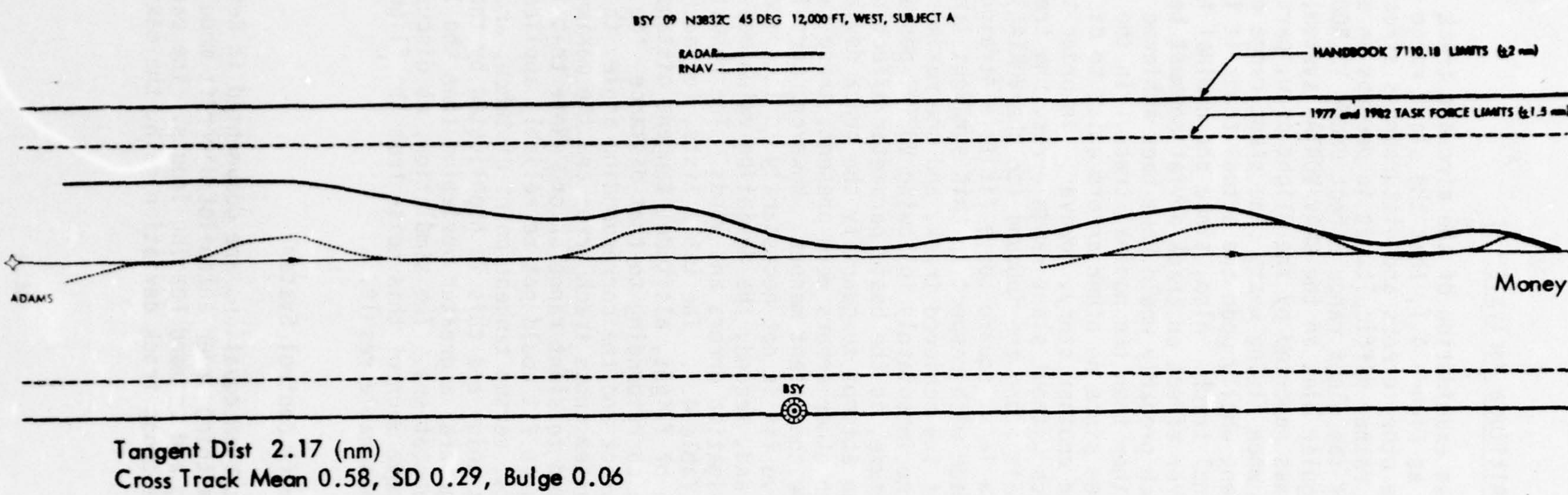


Figure 4.1 Example Aircraft Track and RNAV Guidance Plot

Table 4.1 Slant Range Effect Flight Test Results

Flight	Subject	Direction	Altitude	Tangent Dist. (Nominal)	Tangent Angle (Nominal)	Tangent Dist. (Actual)	Tangent Angle (Actual)	Cross Track $\tilde{x}$	Cross Track σ	Track Bulge
1	A	W	8K	1.32	45°	1.69	38.0°	0.72	0.39	-0.03
10	B	W	8K	1.32	45°	1.88	35.0°	0.63	0.34	0.29
2	A	E	8K	1.32	45°	0.74	60.7°	0.78	0.22	0.49
11	B	E	8K	1.32	45°	0.32	76.3°	0.85	0.40	0.25
3	A	W	8K	0.76	60°	1.32	44.9°	0.65	0.22	0.16
12	B	W	8K	0.76	60°	1.22	47.2°	0.79	0.50	0.25
4	A	E	8K	0.76	60°	-0.02	89.1°	0.75	0.39	0.07
13	B	E	8K	0.76	60°	-0.13	84.4°	1.06	0.27	0.26
7	A	W	12K	1.98	45°	2.10	43.3°	0.45	0.41	0.25
9	A	W	12K	1.98	45°	2.17	42.3°	0.58	0.29	0.06
16	B	W	12K	1.98	45°	2.18	42.2°	0.55	0.47	0.10
8	A	E	12K	1.98	45°	--	--	0.96	0.40	--
17	B	E	12K	1.98	45°	0.49	76.1°	0.93	0.45	0.00
5	A	W	12K	1.14	60°	1.24	57.9°	0.36	0.36	0.21
14	B	W	12K	1.14	60°	1.24	57.9°	0.45	0.41	0.11
6	A	E	12K	1.14	60°	--	--	0.62	0.38	--
15	B	E	12K	1.14	60°	0.20	84.2°	0.70	0.38	-0.03

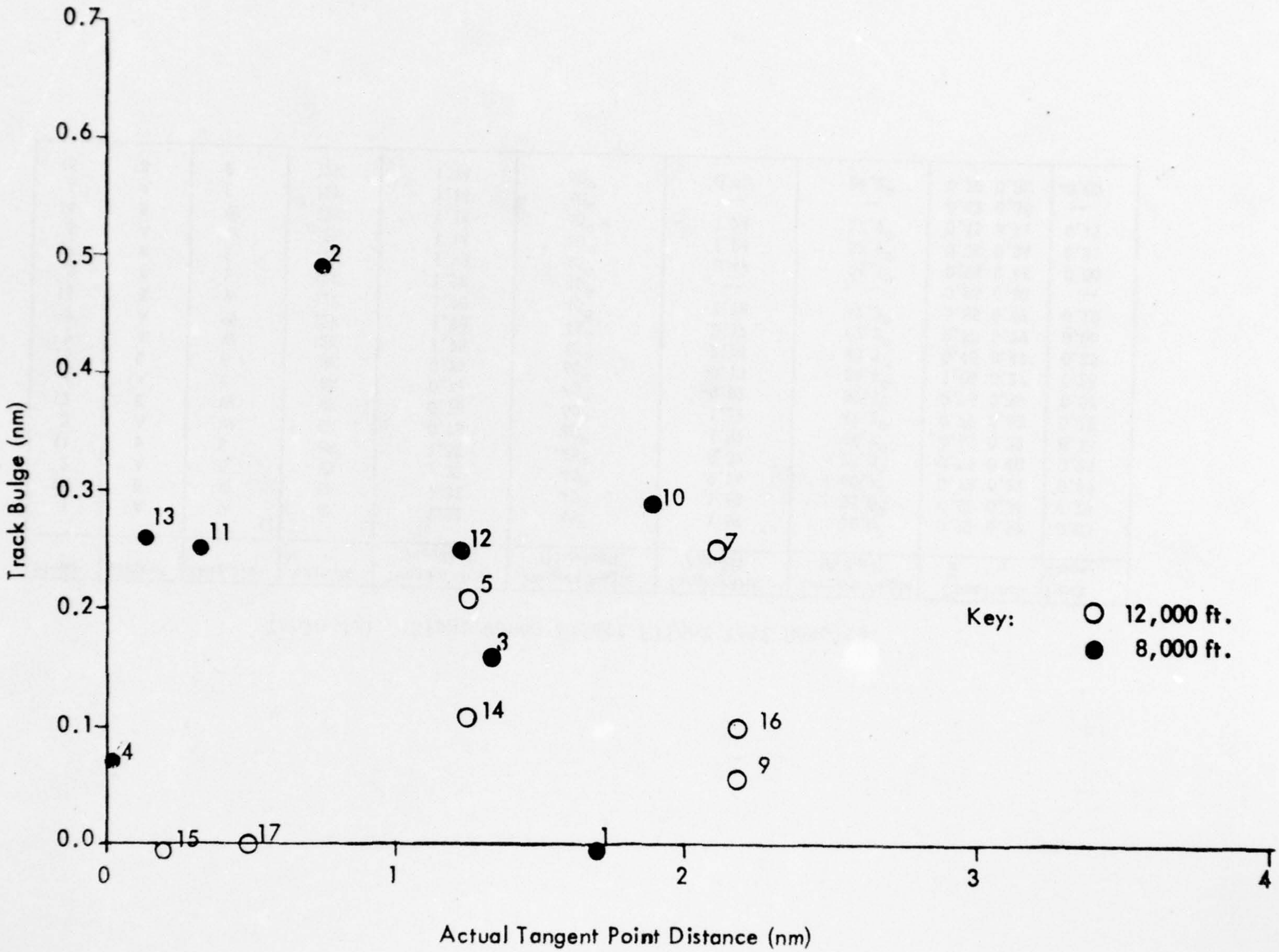


Figure 4.2 Slant Range Flight Test Data

bank angle, and the track acquisition intercept angle. The bank angle limit selected was twenty-five degrees. The cross track deviation gain was selected differently for different aircraft speeds, as discussed below. While the cases simulated are track-following cases rather than track-acquisition cases, the track intercept angle was useful for limiting the heading change which a pilot would take to correct course. After selecting these parameters a stability parameter was adjusted to get the fastest non-oscillatory aircraft response available. To more accurately model the performance of a human pilot, a cross track deviation dead-band was also simulated.

Several aircraft response characteristics were tested in order to ascertain the behavior of the control system. The characteristics which most accurately recreated the behavior of the slant range effect flight tested was the set based upon pilot interviews and an analysis of the track plots. The parameters used were a speed of 160 kt (the speed of the flight test aircraft), a cross track sensitivity of ten degrees heading change per dot of needle deflection, no heading change limit and a dead-band of 0.35 dot (nm). The dead-band value was estimated by examining the aircraft track plots, whereupon it was found that a deflection of at least 0.25 nm and sometimes as much as 0.5 nm was required before a heading change resulted. Likewise, the average heading change resulting from one dot needle deflection was found to be about ten degrees. The track deviation or bulge characteristics of this modeled aircraft system are shown in Figure 4.3 for several values of tangent point distance (note that the VORTAC stations are shown). The resulting bulges, with and without dead-band, are illustrated in Figure 4.4 as a function of tangent point distance.

4.1.2.2 Simulation Calibration

Using the parameters stated above, the track deviations or bulges produced were of the same magnitude as those experienced in the flight tests. It was, however, desired to more accurately correlate the two. A major weakness in the analysis of the flight test data was in determining the effective tangent point distance for each flight, since the value selected additionally impacts the calculation of maximum track deviation. Therefore, means for relating the simulation results to the flight test results were sought. After examining several of the statistical measures available, it was found that the standard deviation of the along track component of slant range error was useful since it implicitly contains tangent point distance information. It is additionally useful since the mean value is always very nearly zero, and therefore one number can characterize the entire situation. The simulations were purposely run over identical track lengths, etc., as the flight tests so that all statistics collected would be comparable. The curves relating the standard deviation of the along track component of slant range error to tangent point distance, as derived from simulation results, are shown in Figure 4.5. Note also that these curves are very insensitive to control system parameter changes of a moderate degree. The standard deviation values change less than 6% when the cross track deviation gain is doubled to twenty degrees per dot deflection at 12,000 ft at a tangent point distance of one mile, for example.

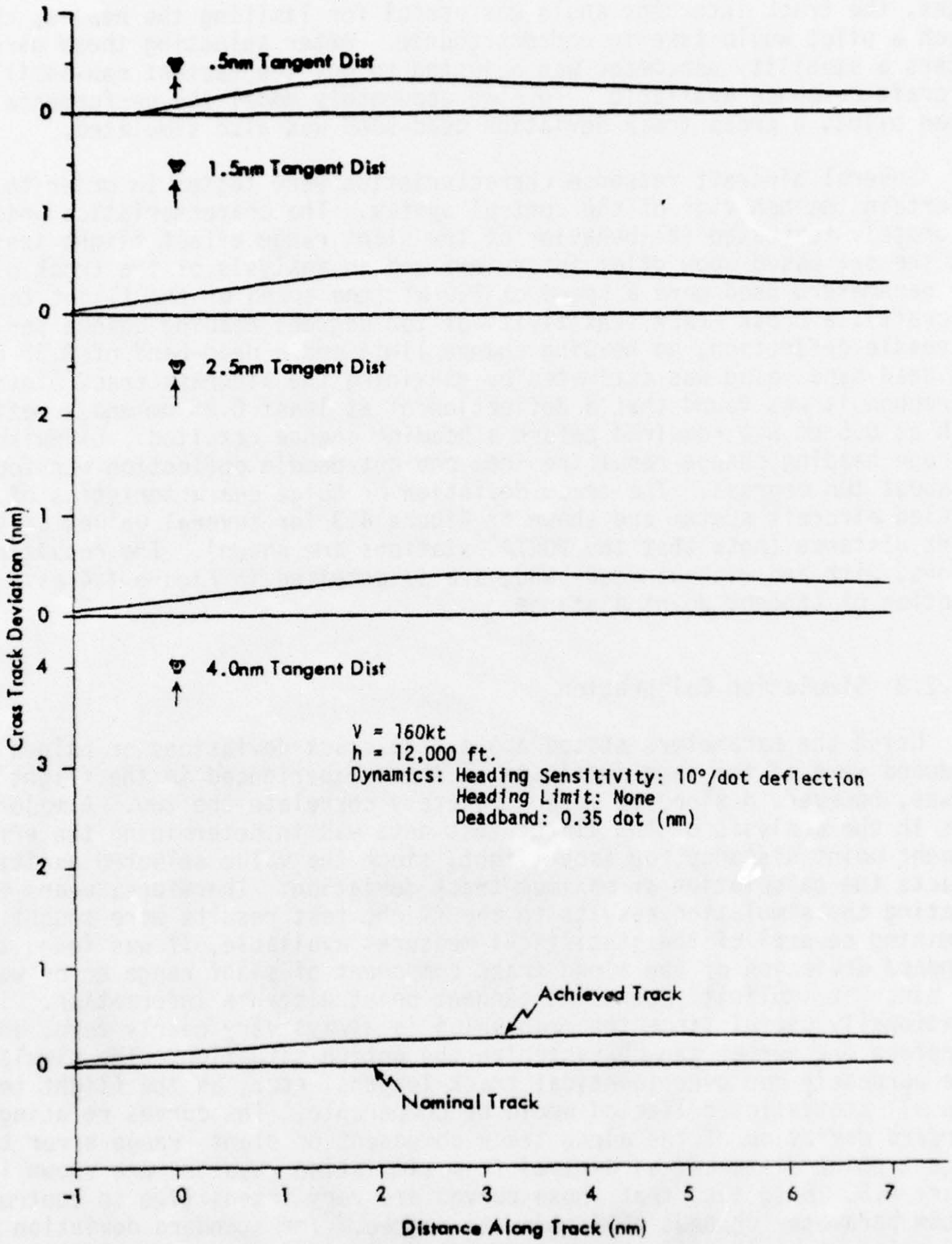


Figure 4.3 Track Deviation Due to Slant Range Error

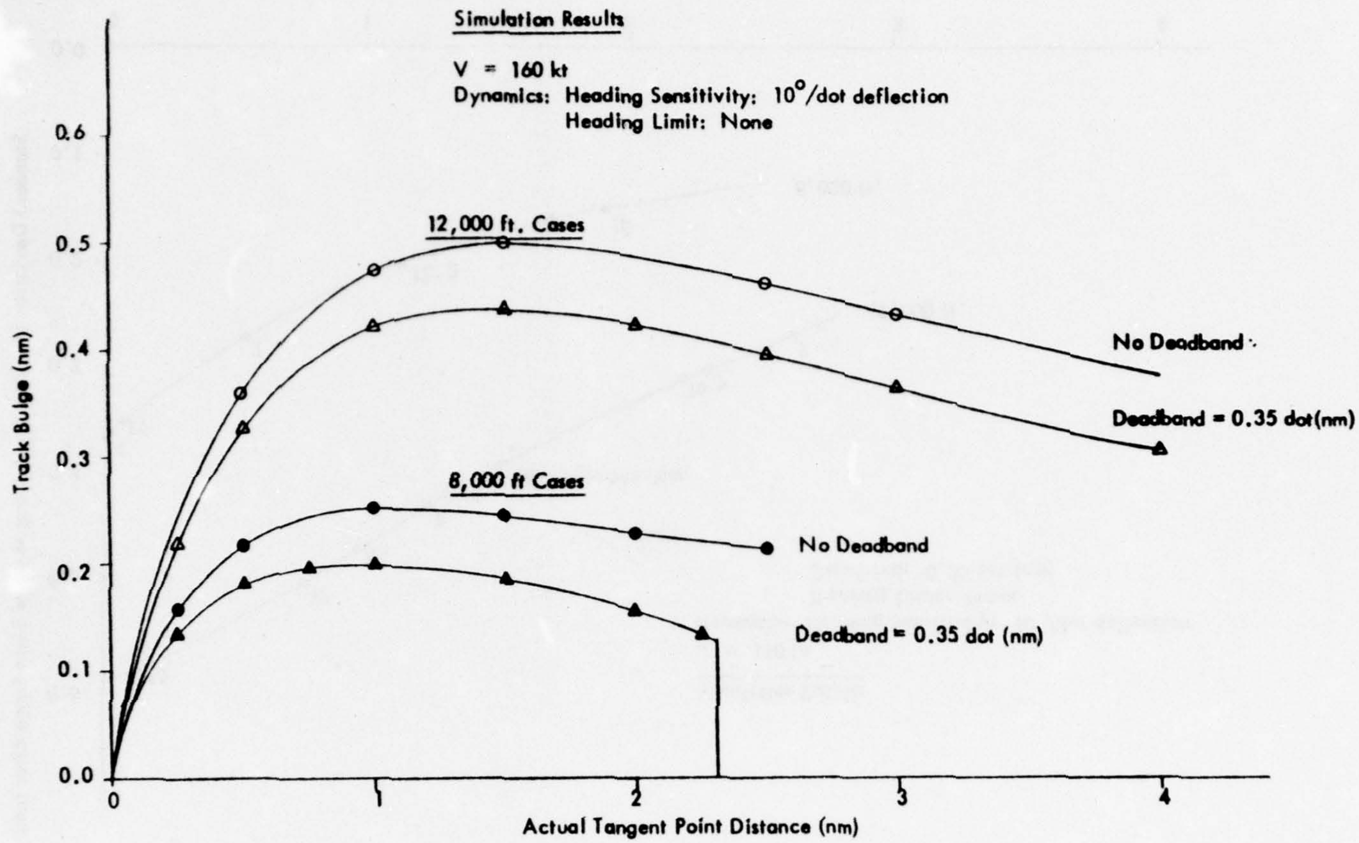


Figure 4.4 Maximum Track Deviation versus Tangent Point Distance

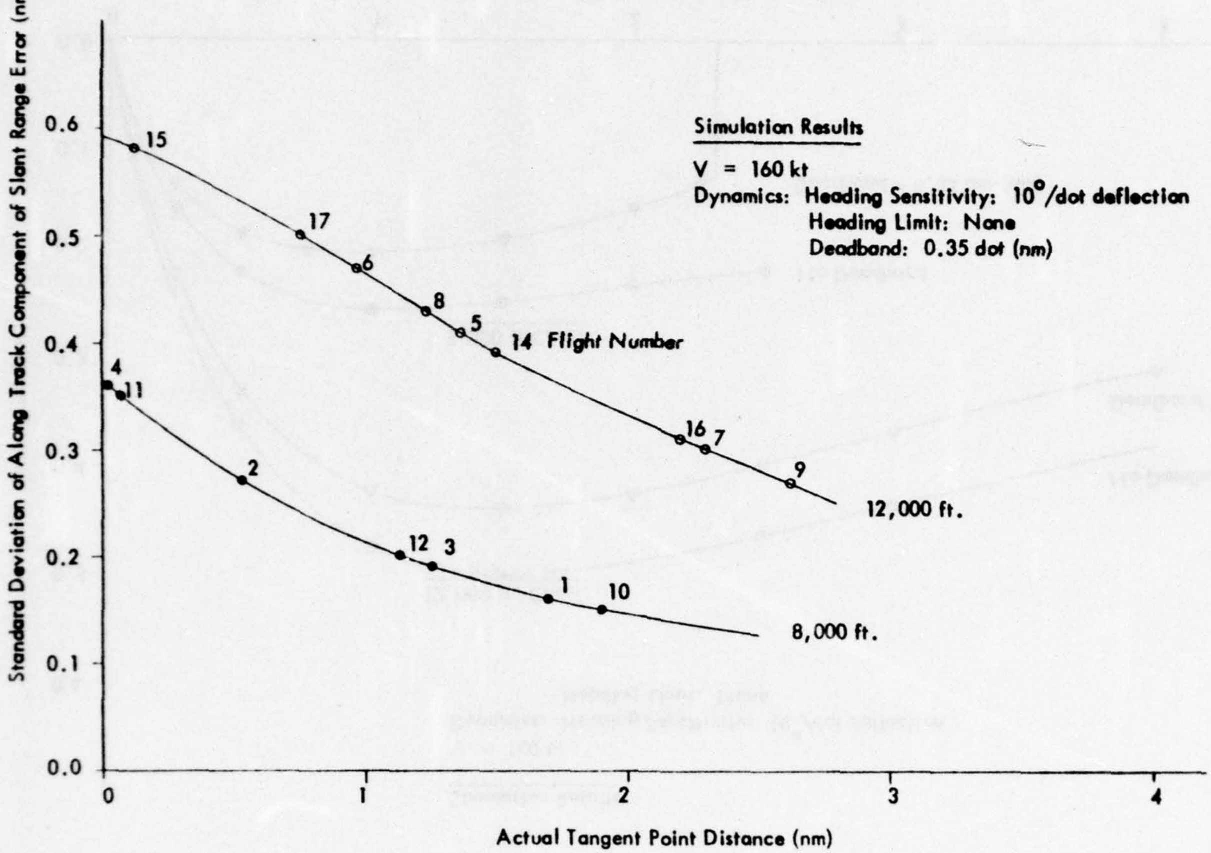


Figure 4.5 Standard Deviation of Along Track SRE versus Tangent Point Distance

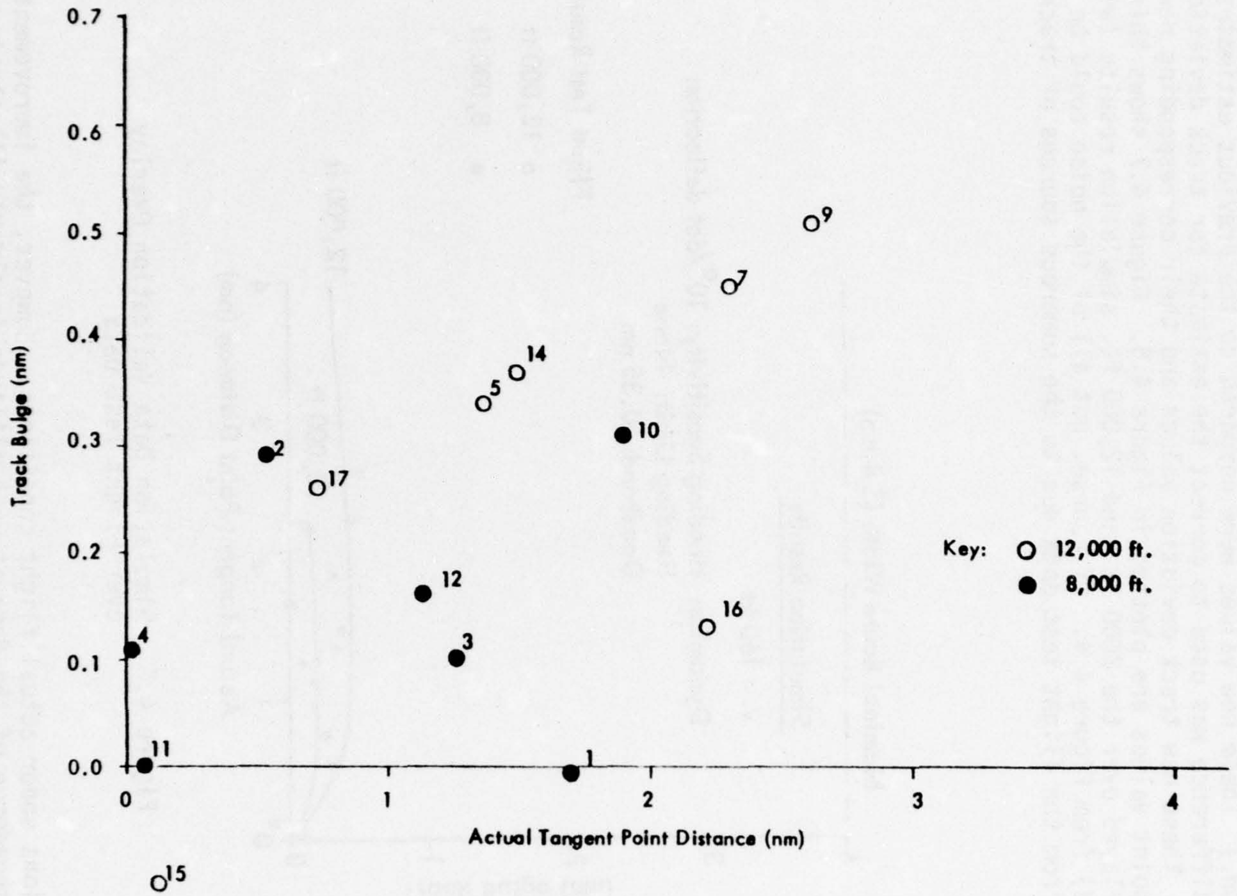


Figure 4.6 Slant Range Data Using Corrected Tangent Point Distance

In order to better evaluate the flight test results, a new tangent point distance was selected for each based on their slant range along track error statistic, as shown in Figure 4.5. (Note that flight 13 does not appear, as its along track error statistic exceeds the values in the simulation.) These new values were compared to the previous estimates, and the difference was used to correct the estimate for track deviation (bulge). These new track deviation values and their corresponding new tangent point values are plotted in Figure 4.6. Figure 4.7 shows this data overlayed over the 8000 ft. and 12,000 ft. simulation results (with dead-band) from Figure 4.4. Of course, not all of the noise could be removed from the flight test data due to the numerous sources of track

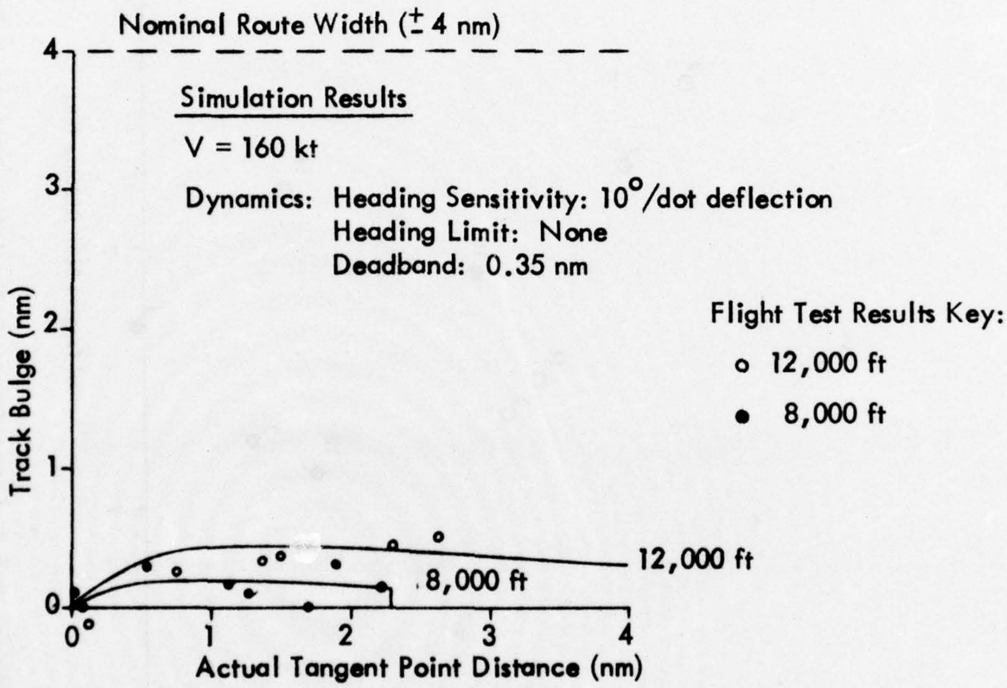


Figure 4.7 Simulation Data Validation Overlay over Flight Test Data

perturbations under actual flight conditions. However, the improvement in the correspondence of the data at each altitude is clearly illustrated, which tends to validate the simulation model as an accurate representation of the flight-tested aircraft/pilot combination.

4.1.2.3 Simulation of the Worst Case Aircraft

In order to ascertain the most serious track deviations to be expected in the low altitude airspace, a slow aircraft with correspondingly severe maneuvers was modeled. It is important to outline the characteristics of this type of aircraft very carefully, and to substantiate the choice of it as being the worst case. As a general rule, larger heading changes are taken by a pilot of slower aircraft in course correction maneuvers than would be the case with faster aircraft. The major reason is that, because of its slow speed, larger angles are required to get back on track in a reasonable period of time. If a fast aircraft were to make such large corrections for normal course deviations, it would overshoot its path and could end up farther off track than before. Even the course corrections used by the pilots of the flight test program (approximated by 10°/dot deflection) were stated by those pilots to be greater than, and to have been applied more rigorously than, the course maneuvers they would apply in the course of normal work as air charter pilots. Thus the 10°/dot figure is probably conservative for the class of light twin used in the test (the 160 kt capability is slower than most twins). The FAA Instrument Flying Handbook [40] recommends, for low speed aircraft, that a heading change of 20° be used for course correction purposes. While no threshold value or specific needle deflection is stated, it is implied by the text and figures that this is for correction of significant deviations from track. In order to interpret this in a conservative manner, the control system gain was set to a response of 20°/dot deflection; however, a heading change limit of 20° maximum was also invoked in order to correspond to the recommendations of the handbook. The course deviation dead-band remained at 0.35 dot (nm), as before, to complete the model of the worst case aircraft.

The slow, responsive aircraft has long been thought to be the one most seriously affected by the slant range problem simply because its maneuverability and speed allow it to respond to the slant range perturbation as the VORTAC is passed, while higher speed aircraft would tend to miss the short-lived effect altogether. This has turned out to be the case, as illustrated by the curves at 8000, 10,000 and 12,000 feet in Figure 4.8. Note that the maximum deviation of 0.72 nm at 12,000 feet is 64% greater than the 0.44 nm deviation of the 160 kt aircraft. For purposes of illustration, the track profiles at 10,000 ft. are shown in Figure 4.9 for several tangent point distances. A faster (200 kt), less maneuverable aircraft was also studied to confirm that the slant range effect on track deviation is less significant in that case than for the flight test case.

The role which this "worst case" type of aircraft plays in IFR operations is of importance here. Data taken from the IFR Peak Day Survey for 1971 [41] is summarized in Table 4.2. The table contains data for only those aircraft which we are presently concerned with: low altitude aircraft which would probably not be required to have an encoding altimeter. As may be seen from this table, 72% of all aircraft concerned file flight plans below 8000 ft., and so do not really have a slant range problem of any significance. The "worst case" type aircraft filing for altitudes above 10,000 ft constitute only 0.4% of those flight plans. This residual number is on the order of

three sigma expectations (99.75%), while route widths are designed around two sigma expectations (95.44%). The maximum deviation from track at 10,000 feet for the "worst case" aircraft is 0.52 nm, and at 12,000 feet is 0.72 nm. These may be considered to be the largest likely deviations due to slant range error in operations below 12,500 feet, since the maximum for the 160 knot aircraft is smaller, 0.44 nm.

TABLE 4.2 IFR PEAK DAY FLIGHT PLAN DATA

Altitude Range	Single Engine 1 to 3 Places (worst case)	Single Engine 4 or more Places	Multi Engine Under 12,500 lb.
Number of Aircraft:			
0 to 7,999 ft.	180	2056	4092
8,000 to 9,999 ft.	35	317	1226
10,000 to 12,999 ft.	35	101	707
(Total Aircraft: 8749)			
Per Cent of Total:			
0 to 7,999 ft.	2.05%	23.50%	46.77%
8,000 to 9,999 ft.	0.40%	3.62%	14.01%
10,000 to 12,999 ft.	0.40%	1.15%	8.08%

4.1.2.4 Impact on Protected Airspace Requirements

The basic standard governing RNAV route widths is Handbook 7110.18 [38]. It includes criteria for expanding route widths due to the slant range effect for low and high altitude enroute and terminal area operations. As stated before, this discussion is limited to operations below 12,500 feet. The additional airspace requirements stated are as follows:

Phase	Nominal Route Width	Altitude	Tangent Point Distance	Expanded Route Width	Along Track Distance
Enroute	± 4.00	$\leq 17{,}000$	2.0-3.0	4.90	$\pm 10.$
Terminal	± 2.00	10,000-17,000	0.9-5.2	4.00	$\pm 5.$
		$\leq 10{,}000$	0.9-2.0	2.85	$\pm 4.$

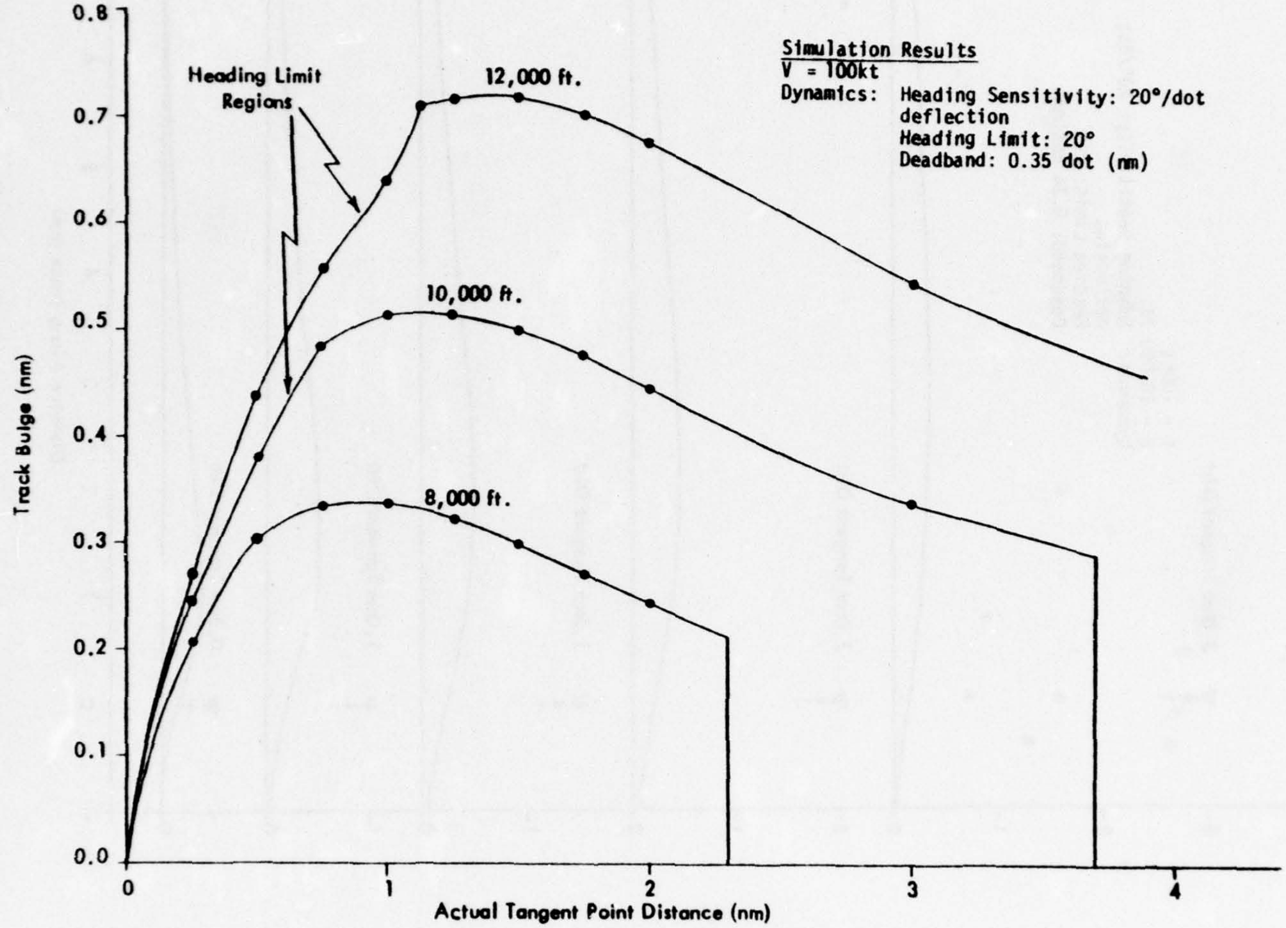


Figure 4.8 Maximum Track Deviation versus Tangent Point Distance

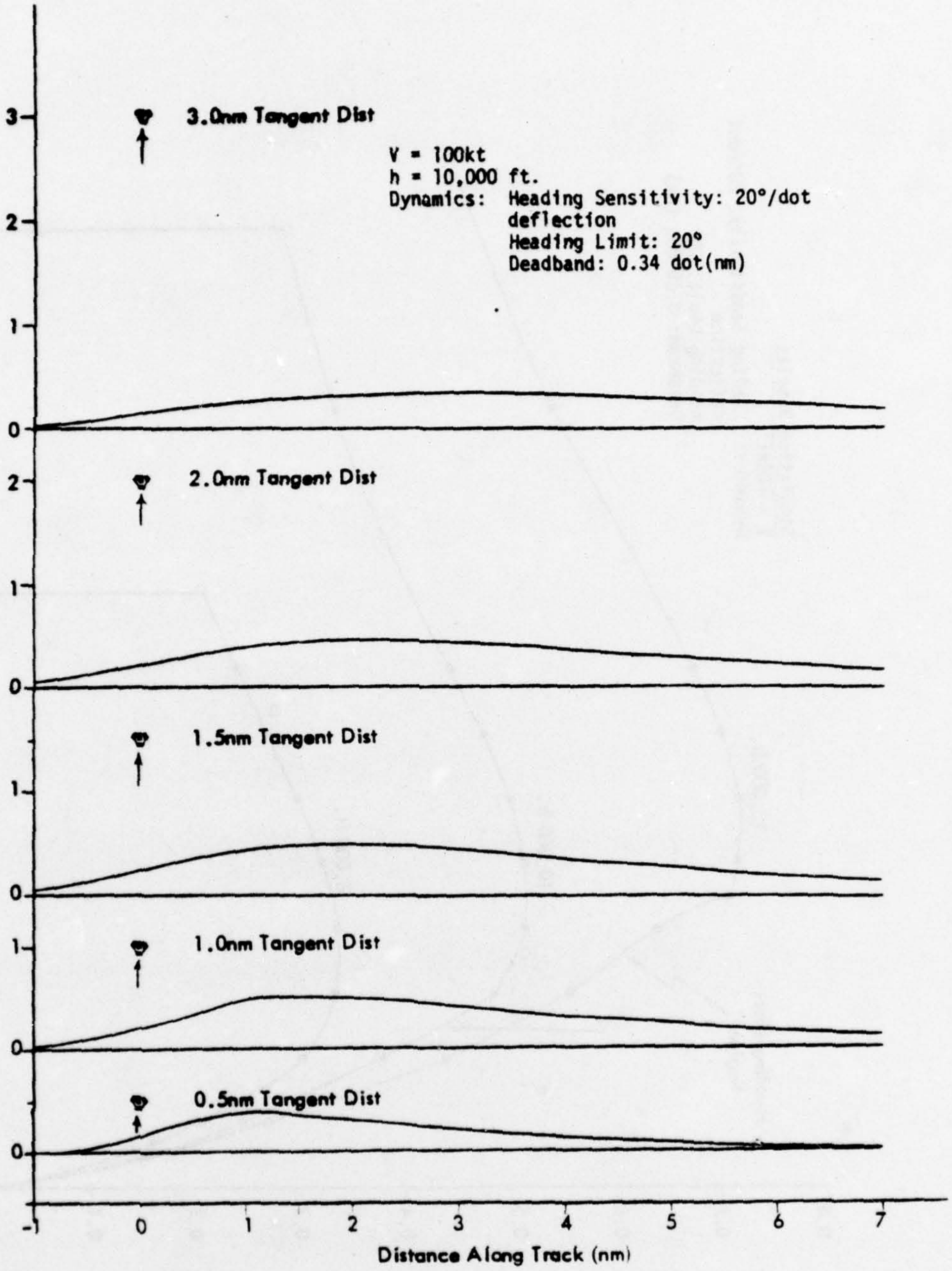


Figure 4.9 Track Deviation Due to Slant Range Error

The expanded route widths are on the VORTAC side of the route centerline only, and extend the indicated along track distance both prior to and subsequent to the station. These values are based upon a mathematical analysis of the slant range guidance error. The flight test/simulation data introduced here is in conflict with these earlier findings, since this data concerns actual aircraft performance under slant range error conditions, not simply guidance error values.

Three major points are raised by this new data. First, the additional protected airspace requirements below 12,500 feet need not be as large as indicated in Reference 38, but may be limited to 0.5 nm (to 10,000 ft) and 0.75 nm (to 12,000 ft). The value indicated in the Handbook for terminal operations at or below 10,000 feet is, for example, 0.85 nm, and would certainly be greater at 12,500 feet. Furthermore, the slant range effect becomes inconsequential below 8000 ft.; therefore SID or STAR route segments constrained at such altitudes when near the reference facility need no additional protected airspace. The second major point is illustrated in Figure 4.10. Note that, except in the case of extremely small tangent point distances where the effect is small, the overall deflection from desired track is less than the actual tangent distance from the actual aircraft track (before passing the VORTAC) to the station, as indicated by the 45° reference line. This simply means that, wherever the aircraft track would have been if there were no slant range error, the aircraft would not be pulled to the other side of the VORTAC by the slant range effect. This means that the presence of a station anywhere between the route centerline and the airspace boundary would not cause any aircraft which would otherwise stay within the protected airspace boundary to exceed that airspace. Therefore, additional slant range airspace need only be provided when the station location is outside of the protected airspace region. This is not reflected in the handbook data, which specifies airspace expansion for VORTAC locations within the normal route width in all three cases listed. The third point of importance is illustrated in Figures 4.3 and 4.9. In all cases the aircraft deviates from track subsequent to VORTAC passage. Therefore, additional protected airspace need only be provided on one side of the station for one-way routes, SIDs and STARs. These figures also illustrate the fact that such protection should be provided for at least five, and probably eight miles along track from the station.

There is an additional way of assessing the protected airspace requirements problem as it is affected by slant range error. It is instructive to look at the impact of slant range error on the probability of remaining within the nominal route width (without expansion). Usually, only a small proportion of the aircraft would be caused to exceed the airspace boundary. For example, if the parameters of the situation were such that a 0.4 nm deviation from track would be expected, only those aircraft which would normally be within 0.4 nm of the airspace boundary would be caused to violate the airspace boundary. Therefore the probability of exceeding the protected airspace (nominally 1-.9544 =.0456) would increase only by the probability of an aircraft being within 0.4 nm of the airspace boundary on side near the VORTAC. This level of probability depends upon the nominal route width, assuming that in each case the route width represents the

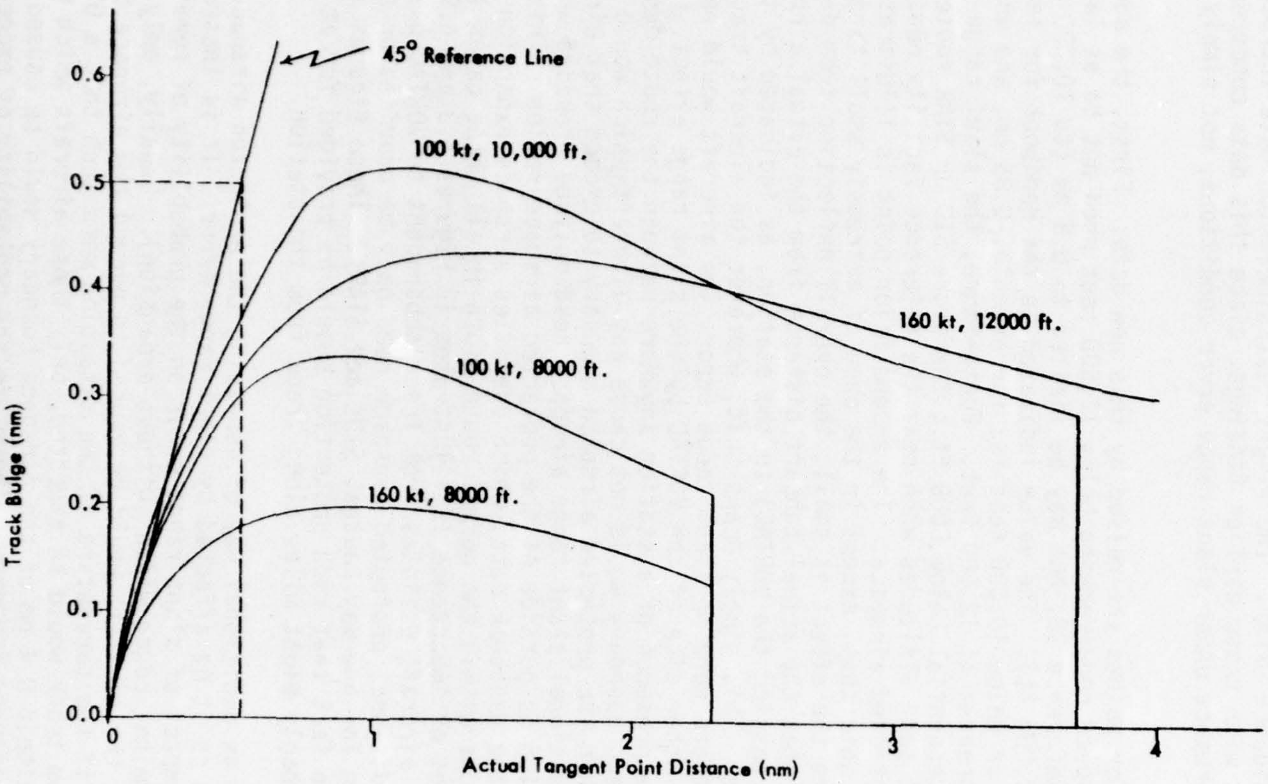


Figure 4.10 Maximum Track Deviation versus Tangent Point Distance

Figure 4.11 Effect of Slant Range Error on Airspace Violations (100 kt, 10,000 ft)

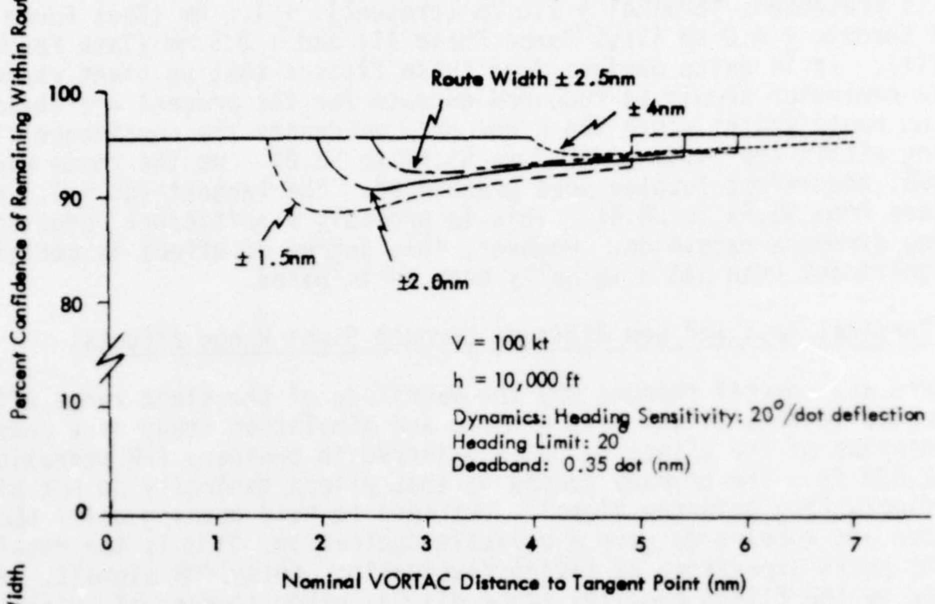
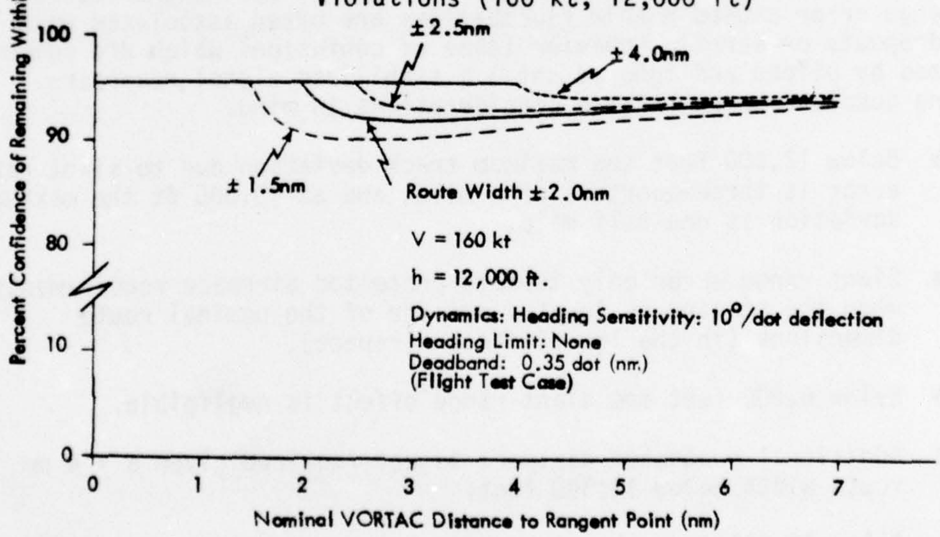


Figure 4.12 Effect of Slant Range Error on Airspace Violations (160 kt, 12,000 ft)



two sigma probability level. Using a $\pm$ 4 mile route width, the probability of being within the outer 0.4 mile is quite small. With a $\pm$ 2 mile route width, it would be significantly larger.

The airspace violation probability has been computed as a function of route centerline tangent point distance using the "worst case" and flight test case data and is presented in Figures 4.11 and 4.12. Data for four route widths is presented: Terminal $\pm$ 2.0 nm (present), $\pm$ 1.5 nm (Task Force Phase II) and Enroute $\pm$ 4.0 nm (Task Force Phase II) and $\pm$ 2.5 nm (Task Force Phase III). It is quite obvious from these figures that no slant range error airspace expansion should be required enroute for the present and Phase II ($\pm$ 4.0 nm route width) since the error only decreases the confidence of remaining within the route width from 95.4% to 93.6%. As the route width is decreased, the effect becomes more pronounced. The largest (at $\pm$ 1.5 nm) is a decrease from 95.4% to 88.4%. This is probably a sufficient reduction for requiring airspace expansion. However, this degree of effect is certainly less significant than had originally been anticipated.

4.1.3 Terminal Area and Low Altitude Enroute Slant Range Effects

There are several reasons why the magnitude of the slant range effect demonstrated in this flight test program and simulation study is a conservative representation of the effect to be experienced in ordinary IFR operations below 12,500 ft. The primary reason is that pilots typically do not blindly follow fluctuating guidance signals, but tend to hold heading until the signal stabilizes and appears to give a reliable indication. This is the result of many long years experience at flying fluctuating, noisy VOR signals. As evidenced by the flight profiles (Appendix E), other sources of guidance noise were present during these flights. Furthermore, the slant range error effect on track, when present, is small compared to wind effects, guidance biases and other error sources. In terms of operational significance, the slant range error caused needle fluctuations are often associated with VOR signal dropouts or erratic behavior (zone of confusion) which are commonly recognized by pilots and ignored until a stabilized signal reappears. The following conclusions bear these considerations in mind.

- Below 12,500 feet the maximum track deviation due to slant range error is three-quarters of a mile, and at 10,000 ft the maximum deviation is one-half mile.

- Slant range error only impacts protected airspace requirements when the station is located outside of the nominal route dimensions (in the low altitude airspace).

- Below 8,000 feet the slant range effect is negligible.

- Additional protected airspace is not required given a $\pm$ 4 nm route width below 12,500 feet.

- Below 12,500 feet the slant range error effect is an operational problem of minor significance rather than a major accuracy problem.

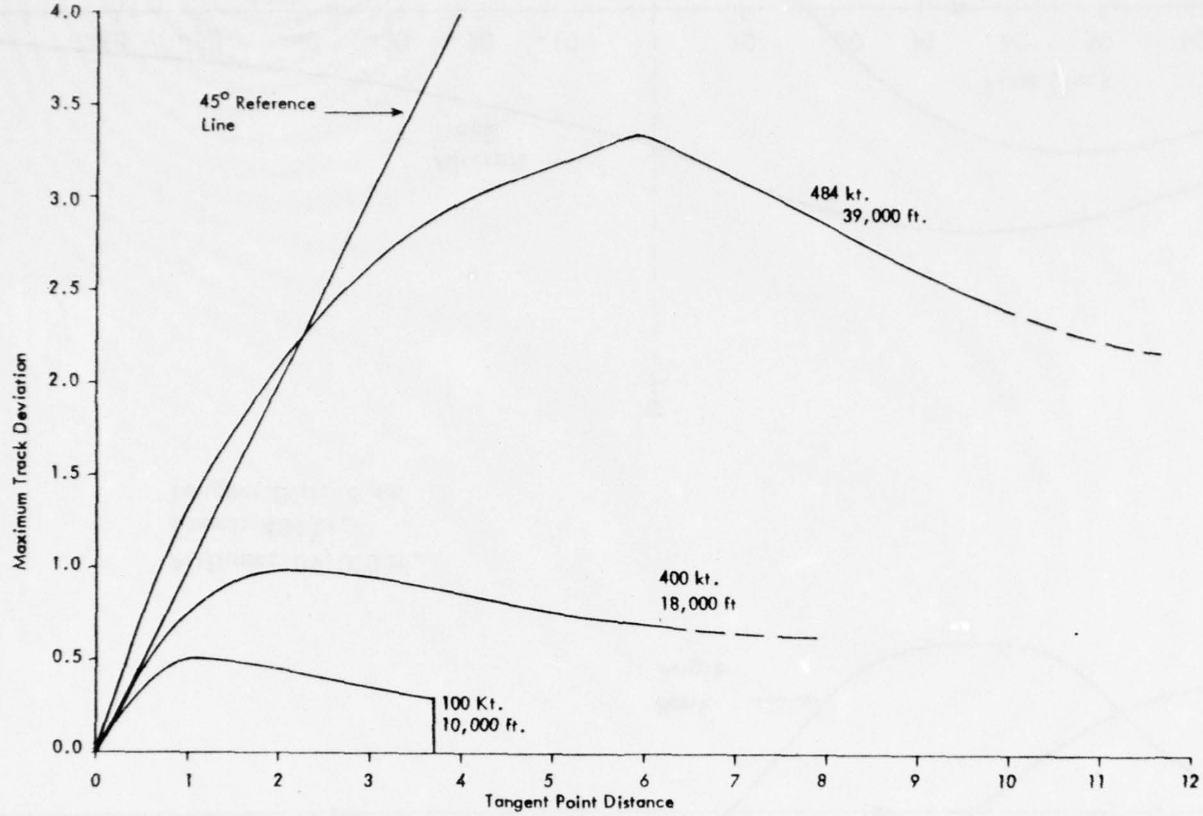


Figure 4.13 Maximum Track Deviation for Intermediate and High Altitude Jet Aircraft

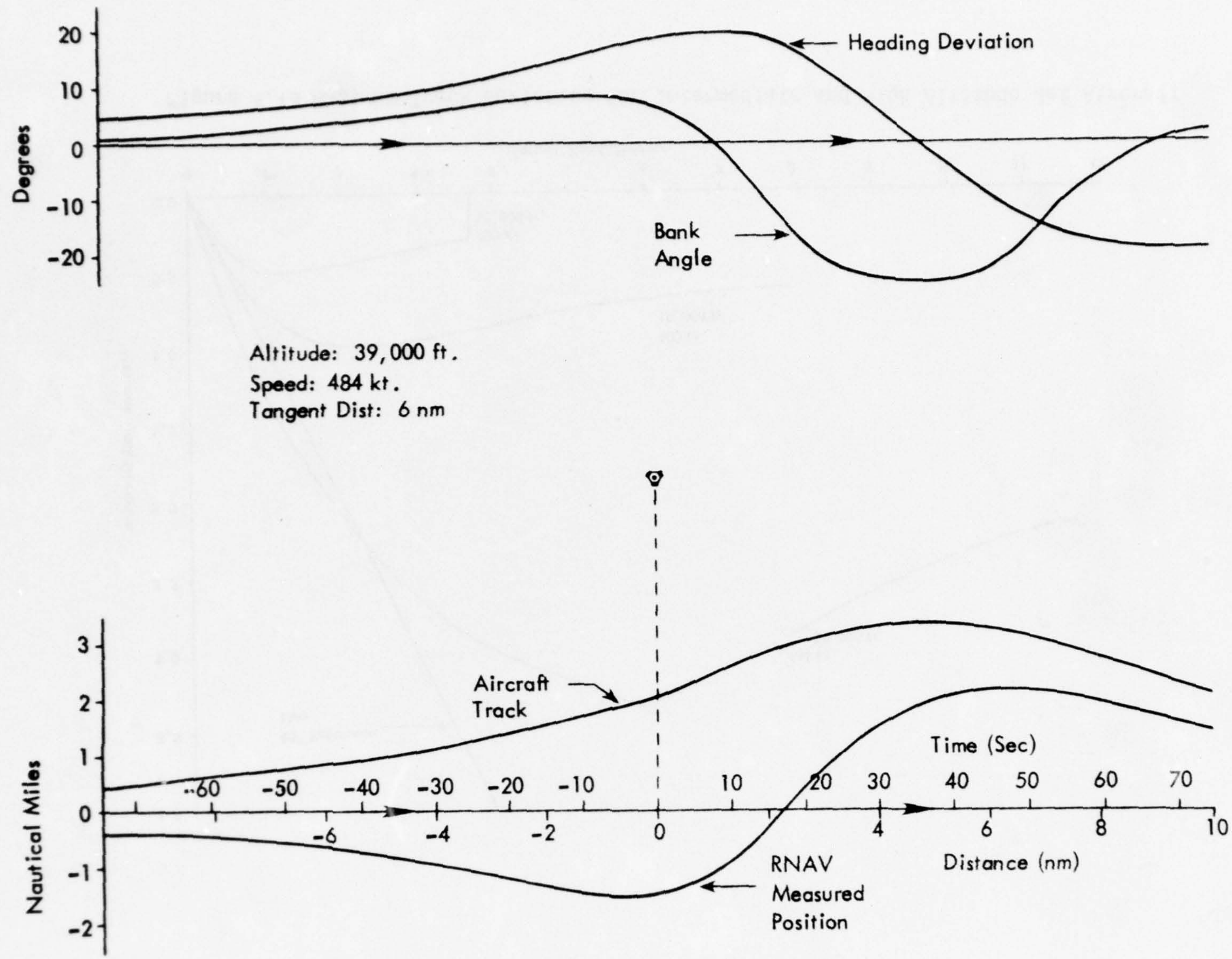


Figure 4.14 Achieved Track and Dynamic Response (39,000 ft)

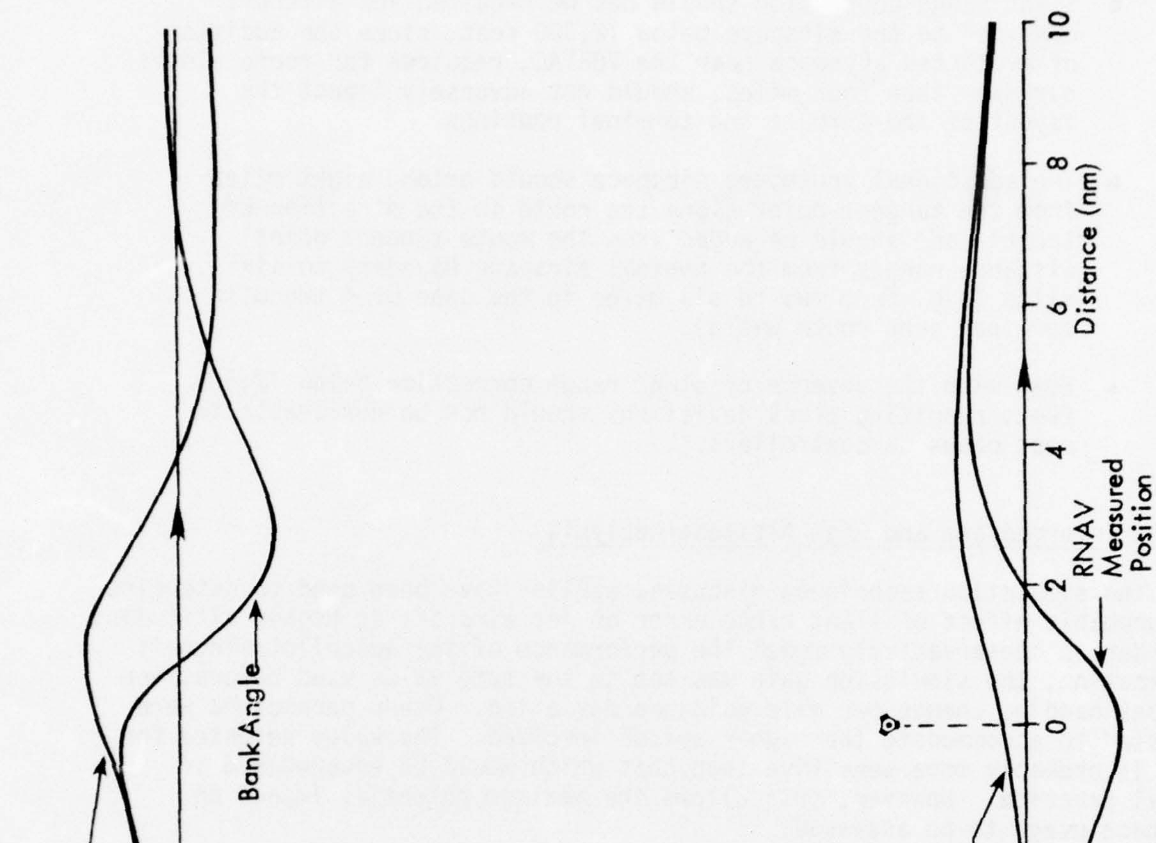


Figure 4.15 Achieved Track and Dynamic Response (18,000 ft)

- Slant range correction should not be required for aircraft confined to the airspace below 12,500 feet, since the addition of protected airspace near the VORTAC, required for route widths narrower than four miles, should not adversely impact the layout of the enroute and terminal routings.

- The additional protected airspace should extend eight miles from the tangent point along the route in the direction of travel, and should be added when the route tangent point distance ranges from the nominal airspace boundary to six miles (e.g. from two to six miles in the case of ± two mile terminal area route width).

- Even with the absence of slant range correction below 12,500 feet, resulting track deviations should not be noticeable in most cases to controllers.

4.1.4 Intermediate and High Altitude Analysis

The simulation techniques discussed earlier have been used to determine the probable effect of slant range error on jet aircraft at higher altitudes. In order to conservatively model the performance of the autopilot/aircraft combination, the simulation gain was set to the same value used before, ten degrees heading change per mile guidance deviation. Other parameters were adjusted to accommodate the higher speeds involved. The value selected for gain is probably more sensitive than that which would be encountered in actual practice. However, this allows the maximum potential impact on airspace usage to be assessed.

Two cases were studied, a jet aircraft at 18,000 ft. cruising at 400kt TAS, and a high altitude cruise (39,000 ft.) at 484kt TAS (M =.84). As before these cases were simulated over a range of tangent point distances. The resulting maximum track deviations are plotted as a function of tangent point distance in Figure 4.13. Note that the worst case data (100kt) is plotted for comparison. It is obvious from the figure that slant range correction (or an approximation to it) would be required in the case of the higher altitudes, since track deviations in excess of three nm would occur. Over and above the question of airspace boundaries, however, is the impact which the uncompensated error would have on cockpit procedures and passenger comfort. Figure 4.14 is a plot of the aircraft track for the six-mile tangent distance case. While the aircraft track is a smooth curve, it is very instructive to examine the behavior of the RNAV guidance signal and aircraft dynamic response more closely. The RNAV position indication is plotted on the same axis. The slant range effect causes a fly-left indication while approaching the station, causing the aircraft to deviate to the left. This occurs quite smoothly and unnoticeably as is demonstrated by the bank angle and heading plots in that figure. The bank angle remains at four or five degrees throughout the approach to the station, and would remain unnoticed by the flight crew until a considerable heading deviation had been accumulated. However, once the station is passed, a "whiplash" effect occurs: since the aircraft is left of track and the slant range error

component is diminishing rapidly, a large (two mile) fly-right indication is produced quite quickly. In addition, the heading deviation is now in the wrong direction and combines with the RNAV indication to cause a roll to the right to the bank limit (25°) in order to produce the prescribed change in heading. Obviously, this is not suitable as a routine enroute procedure, and so indicates a requirement for slant range error compensation.

In addition to the disturbing dynamics associated with nearby passes to the VORTAC station, there are additional reasons for requiring slant range correction in the high altitude environment. Primarily, at high altitudes the slant range error effect is not a localized effect, but would impinge upon airspace requirements for almost all high altitude routes. For example, at 39,000 ft. an RNAV guidance error of one mile (at the tangent point) exists at a distance of 21 miles from the station, one-half mile at 41 miles, and one-quarter mile at 83 miles away. Since nearly all RNAV routes pass within fifty miles or so of the reference stations, and since the error levels change so slowly at those distances that the aircraft/control system would track them, additional protected airspace would be required.

The case for slant range correction for aircraft flying at intermediate altitudes (12,500 to 18,000 feet) is not nearly so clear-cut. Figure 4.15 shows that the maximum course deviation at 18,000 feet to be one mile for a 400 knot aircraft. (A slower aircraft would deviate much further, however). One mile of additional protected airspace in the region of the VORTAC between 12,500 and 18,000 feet would probably be sufficient to resolve the slant range error problem from an airspace point of view. However, the aircraft dynamics associated with the guidance error (see Figure 4.15), while not nearly so severe as in the high altitude case, still supports the case for requiring slant range correction. This is particularly true in light of the fact that encoding altimeters, which are the most costly part of the slant range correction process, will be required in that airspace. If necessary in order to minimize costs, approximate correction techniques could be allowed. Approximations could include an assumed mean station elevation, or the use of curve-fit approximations to the root-difference-square correction computation. Existing systems could thus be upgraded with the simple addition of a DME signal pre-processor or similar device separate from the existing RNAV equipment. These approximate techniques would be suitable due to the limited range of altitudes to be accepted (0 to 18,000 ft).

4.1.5 Intermediate and High Altitude Slant Range Effects

- If left uncorrected, slant range error would produce unacceptable airspace expansions affecting nearly all high altitude enroute segments.

- Above 12,500 feet, the slant range error can produce signal fluctuations and dynamic reactions which could be disturbing or misleading to the flight crew.

- Slant range correction is required above 18,000 both to conserve airspace and for purposes of passenger comfort and guidance signal integrity.

- Some form of slant range correction should be required above 12,500 feet.

- Approximate techniques for slant range correction should be considered for suitability for operations between 12,500 and 18,000 feet.

4.1.6 Effect of Slant Range Error on Route Placement and RNAV Maneuvers

The results of the analysis in this section indicates that if slant range correction is required above 12,500 ft. MSL, the only area where slant range error will have any impact is between 8,000 ft. and 12,000 ft. in the terminal area. The seven terminal area designs described in Reference 2 were examined to determine if the requirement for additional route width in the vicinity of VORTACs, or described in Section 4.1.3, would have any impact on route placement, and it was determined that there was no impact on any of the designs. The potential impact of slant range error on the utilization of RNAV maneuvers in the terminal area is also negligible. Of the two route deviation maneuvers used, "direct to a waypoint" and "parallel offsets", only the latter has any route width connotation. As pointed out in Section 4.1.2, route widths are established on the basis of assuming that aircraft will remain within the specified route width 95.4% of the time. Slant range effects between 8,000 and 12,500 feet will cause only a slight reduction in that percentage and will be indistinguishable to the controller from other navigation error induced excursions.

4.2 ENROUTE HIGH ALTITUDE VORTAC REQUIREMENTS

This phase of the ATC system impact analysis was conducted to identify the modifications to the existing VORTAC system, and the associated implementation costs, which would be required to support both charted and preplanned direct structures in the high altitude enroute environment. These modifications were determined specifically for route width-error budget combinations recommended by the RNAV Task Force [1], for operations at altitudes between 18,000 and 45,000 feet. The modifications considered included addition of new stations and upgrading of existing stations to provide high altitude coverage. This study assessed only the overall scope of the requirements for high altitude VORTAC coverage. Determination of the specific, individual station requirements must be based on an implementation route structure yet to be developed. This study also did not consider the removal of high altitude stations not needed for high altitude coverage because of their possible use in providing full low altitude coverage, a subject which was not addressed in this study.

In a previous study [12], preliminary estimates of potential modifications to the existing VORTAC system necessary to support charted and preplanned direct RNAV were made based on the assumption that certain postulated improvements to the VORTAC system would be accomplished [1]. Several alternatives were considered, including addition of new stations, bending of routes around coverage gaps, selectively increasing minimum enroute altitudes, and the utilization of variable route width requirements. In the current study, in addition to further consideration of minimum enroute altitudes, five other techniques were identified and evaluated as candidates to enhance the current VORTAC system to the point where the required navigation coverage could be achieved:

(1) Converting low altitude VOR/DMEs to high altitude operations.
(2) Converting low altitude VOR/DMEs to high altitude operations. and upgrading bearing error performance through the use of DVOR.
(3) Upgrading the bearing error performance of existing high altitude VOR/DMEs through conversions to DVOR.
(4) Establishing new VOR/DME stations.
(5) Establishing new VORTACs with improved bearing error performance attained through the use of DVOR.

The VORTAC system requirements, subsequently presented in this section, were determined by estimating the most cost-effective combination of these five system enhancing techniques for each postulated set of RNAV system conditions.

4.2.1 Methodology

The study was structured to identify the impact on the VORTAC system necessary to provide coverage for both charted and preplanned direct (total CONUS) route structure coverage in the high altitude enroute environment for certain combinations of route width and navigation error budgets. The charted RNAV route structure utilized in the analysis was the 429 airport pair structure developed by NAFEC [4]. The route widths selected

were a constant ±4 nm and ±2.5 nm, which correspond to the Task Force recommended route widths for the 1977 and 1982 implementation periods respectively. The corresponding error budgets recommended by the Task Force are given in Table 4.3.

The 1977 case was analyzed with the primary goal of providing coverage at an altitude of 18,000 feet for the 429 airport pair RNAV route structure designed by NAFEC. However, this case was also evaluated for full CONUS coverage and at altitudes of 24,000 and 30,000 feet in addition to the baseline altitude. The 1982 case was evaluated to full CONUS coverage at 18,000 feet. Implementation cost sensitivities as a function of route width and flight technical error for each of four selected error budget sets were derived from a parametric analysis. Information is also presented to permit the reader to derive VORTAC system requirements for virtually any other error budget-route width combination and to modify the total implementation cost should it become necessary to adjust one or more of the unit costs used in this study. VORTAC frequency protection was examined primarily for the 1977 case. Because of the long term possibility of closer channel spacing and the potential elimination of high altitude NAVAIDs which may not be required in a total high altitude RNAV environment, a sophisticated frequency protection analysis for the "1982" period was not conducted.

The possibility of using $\rho - \rho$ in lieu of ρ-θ navigation was also explored with requirements defined for both the NAFEC 1977 RNAV route structure and full 1982 CONUS coverage at 18,000, 24,000 and 30,000 feet, respectively.

Table 4.3 Task Force Recommended Route Widths and Error Budgets

Implementation Period	1977	1982
Recommended Route Width	±4 nm	±2.5 nm
Recommended Error Budget		
Flight Technical Error	1.0 nm	1.0 nm
Ground VOR	1.5°	1.0°
Airborne VOR	1.5°	1.0°
Ground DME	0.1 nm	0.1 nm
Airborne DME	0.5 nm	0.25 nm
Airborne Computer	0.25 nm	0.25 nm

The methodology adopted to estimate the VORTAC requirements for any given set of route width and navigation accuracy constraints consists of the following steps:

(1) Convert the route width and navigation accuracy requirements, including station bearing error, into a maximum VORTAC coverage distance (radius);
(2) Determine limits on coverage patterns of each high altitude VORTAC based upon terrain, signal strength and frequency protection considerations;
(3) Impose the results of Step 2 as an additional constraint on the coverage patterns obtained in Step 1;

(4) Aggregate the station coverage patterns to determine which portions of designated RNAV route structures or areas of the CONUS airspace do not have adequate coverage; and

(5) Examine the alternative methods to fill the coverage gaps and identify characteristics and costs associated with those that produce the most cost-effective solutions.

This process was repeated as necessary to address the various system requirements. The specific methodology applied in each of these areas will be described in detail in the following subsections.

4.2.1.1 Individual Station Coverage

Fundamental to the VORTAC requirements study was the determination of the effective coverage area of each ground VORTAC station. The means by which this coverage can be determined is a direct result of the requirements imposed upon the VOR and DME signals. These are as follows:

(1) The signal errors must be sufficiently low to satisfy the specified navigation accuracy requirements.

(2) The signals must be free from interference, specifically interference from other stations whose signals would produce erroneous information.

(3) The signals must be receivable within the station's service volume.

Navigation errors result from a variety of sources in addition to the ground station. The current error budgeting practice (outlined in AC-90-45A) [19] assumes independent normal error distribution, which allows the use of a root-sum-square (RSS) technique to estimate overall cross-track error based on the error components. Large VORTAC station errors logically produce large navigation errors. The DME signal error, as well as its cross track impact, is generally accepted not to be a function of range. Such is not the case with the VOR signals, however. While the signal itself may degrade only slightly as the range increases, its impact on aircraft position error increases linearly with range. Based upon the RSS equations, if values for all of the component errors are assumed, the usable range of a station can be determined by the following equation:

$$R = \frac{\sqrt{W^2 - C^2 - \rho_G{}^2 - \rho_A{}^2 - F^2}}{\sqrt{\theta_A{}^2 + \theta_G{}^2}} \qquad (4.1)$$

where

R = range (nm)
W = desired route width (nm)
C = airborne computer error (nm)
ρ_G = ground DME error (nm)
ρ_A = airborne DME error (nm)
F = flight technical error (nm)
θ_A = airborne VOR receiver bearing error (radians)
θ_G = VOR transmitter bearing error (radians)

The route width, W, is assumed to be synonymous to the 2 σ value for cross track error. The equation provides appropriate results when 2 σ values for the component errors are utilized.

The second requirement imposed upon VOR/DME signals stems from frequency protection considerations. The current practice is to insure frequency protection for high altitude VORTACs out to a distance of 130 nm. This implies that an aircraft anywhere within 130 nm of its selected station would not be able to receive signals from any other station of the same frequency, nor would the signals to be interfered with by stations on adjacent frequencies (the manner in which this frequency protection is insured is discussed in Section 4.2.1.5). Only extreme combinations of large route widths and small navigation errors permit the use of VORTAC stations at distances beyond the current regulatory limit. While a reduction in the frequency protection radius would have no impact on the current stations, an expansion of the service area, as would be necessary to provide a greater coverage radius, may induce frequency protection violations which would not otherwise exist. For these reasons, the current frequency protection radius of 130 nm was imposed as an upper bound for all station coverage addressed in this study.

The previous two requirements serve to insure that the VORTAC signals are sufficiently accurate and free from interference. Whether or not the signals are receivable is the final area of concern. Terrain effects and signal strength must be considered. The data necessary to establish the coverage patterns for each of the high altitude VORTACs was available, at least in part, from two independent data sources; random coverage data (RACO) [42] and Electromagnetic Compatability Analysis Center data (ECAC) [43].

The ECAC data was generated by an analytical procedure using topographical information measured every 30 seconds of latitude and longitude (1/2 nautical mile). This grid-oriented information was used to establish the horizon angle for each one degree radial surrounding each station. The coverage distance along each radial was then computed based upon the horizon angle and the altitude at which coverage is desired, of which a total of eight were considered. The RACO data were derived primarily from flight inspections predicated on flying the 5 micro-volt signal strength contour around the stations at an altitude of 18,000 feet.

While both of these data sources provide highly reliable information, each has its disadvantages. The ECAC data does not reflect signal strength, accuracy or scalloping peculiarities. Further, its ability to properly predict coverage based upon geographical considerations is constrained by the grid size and the topographical accuracy. Errors in the RACO data can be caused by the inability of the test aircraft to follow the 5 micro-volt contour. This is particularly true when highly irregular contours are encountered and is most severe when the signal is lost due to obstructions. The point of "regained signal" is not necessarily on the 5 micro-volt contour and the measured radial distances to the station could be somewhat erroneous until the aircraft regains its desired 5 micro-volt course.

Since both of these data reflect contour irregularities caused by terrain obstructions, but only the RACO data is influenced by signal strength, the RACO data would be expected to provide the more conservative (and accurate) results. Two examples of coverage patterns consistent with this expectation are presented in Figures 4.16 and 4.17. Counter examples, however, are also available. These plots are based upon a data point every 10 degrees. This granularity was utilized for the VORTAC study for reasons of computer efficiency, even though the ECAC data is available in one degree increments. The VORTACs illustrated in Figures 4.16 and 4.17 have areas where the RACO coverage radii were apparently foreshortened by signal strength rather than terrain (south and west of ABQ., for example). In other directions, the ECAC and RACO data are reasonably consistent. In theory, the RACO contour should be contained within the ECAC contour. Inaccuracies in either of the data bases, however, can result in longer RACO radii, examples of which can be found in both of the previously mentioned figures.

There were 194 high altitude VORTAC stations for which both RACO and ECAC data were available. The data for these stations were compared to ascertain both their degree of consistency and to fully establish that the RACO data is the more conservative. The results are summarized in Table 4.4.

For reasons of frequency protection, coverage distances in both data sets were truncated at 130 nm. The larger differences between the ECAC and RACO data anticipated to occur at distances greater than 130 nm from the stations were not considered and, therefore, did not influence the comparison results. While most of the results indicated that the RACO data provided, as expected, smaller more conservative coverage patterns, it can be seen that the ECAC data did in fact produce a smaller coverage area for virtually one quarter of the stations considered. The resulting average discrepancy of the overall radii was only 3.5 nm, a reasonably small figure.

This study focused on the coverage patterns at FL180, the lower limit of the high altitude airspace. Both sources of data, RACO and ECAC, provided data directly usable at this altitude. For certain portions of the study, the coverage patterns at higher elevations were obtained via linear extrapolation. This was a slightly conservative approach in that the tendency of the radio waves to bend toward the earth as they ascend in altitude (thereby providing greater coverage) was not taken into account.

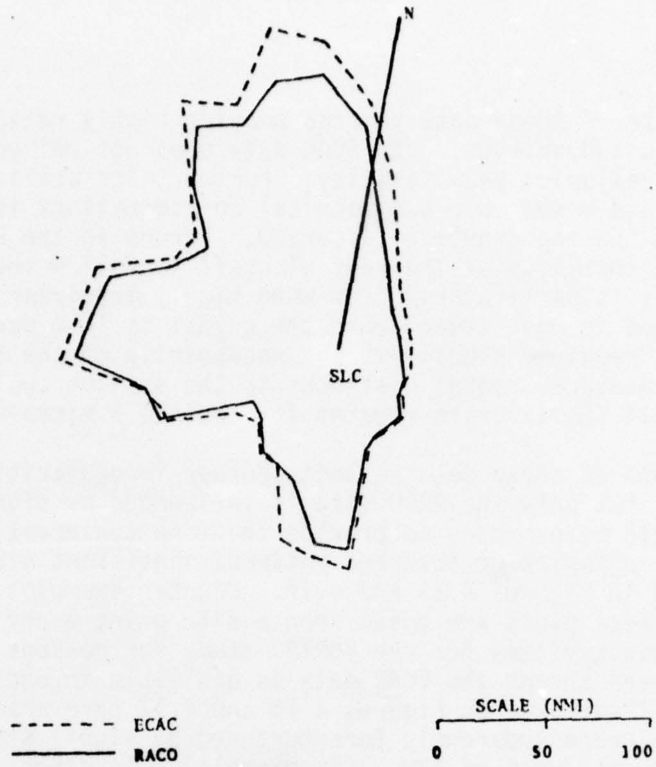


Figure 4.16 RACO and ECAC Coverage Patterns for the VORTAC (SLC), Salt Lake City

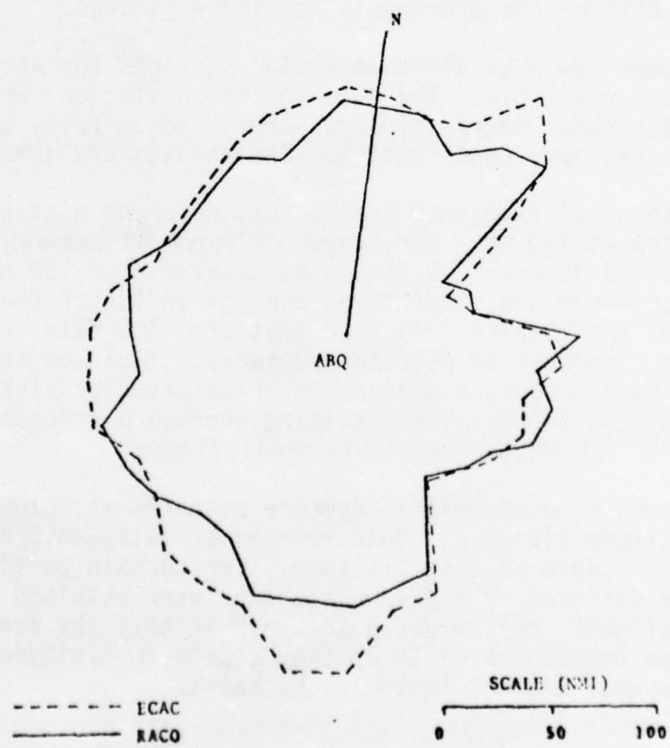


Figure 4.17 RACO and ECAC Coverage Patterns for the VORTAC (ABQ), Albuquerque

Table 4.4 ECAC/RACO COMPARISON SUMMARY

(based on data from 194 high altitude VORTACs)

	RACO	ECAC
Average Coverage radius (nm)	121.2	121.4
Average Coverage area (sq.mn)	40,059	47,225

Average discrepancy between individual radii = 3.5 nm

Percent of RACO radii which were shorter than ECAC = 87.7

Number of Stations with smaller average RACO radius = 146 (75.3%)

Number of stations with smaller RACO coverage area = 148 (76.3%)

Comparison of the Number of Stations with equivalent coverage		ECAC	
		constant 130	irregular
RACO	Constant 130	107	18
	Irregular	6	63

At the time that the VORTAC study was initiated, with the consideration of the current high altitude VORTAC Stations, the ECAC data was only partially available. As a result of the aforementioned comparions and data availability factor, this study used the more conservative RACO data with the ECAC being used, subject to its availability,in a supplementary manner when RACO data was not available.

4.2.1.2 Coverage Gaps

Having established the procedures whereby the coverage pattern of a given station can be determined, the next task involved the identification of the coverage patterns produced by an aggregated set of individual VORTACs. From this information the areas where no coverage occurred, i.e., coverage gaps, could be defined. Two distinguishable sets of VORTACs were used in this study. Specifically, high altitude VORTACs used for navigation between 18,000 and 45,000 feet and low altitude VORTACs providing navigation signals for aircraft below 18,000 feet. Selected Canadian VORTACs which can be used to provide coverage within the CONUS are also included.

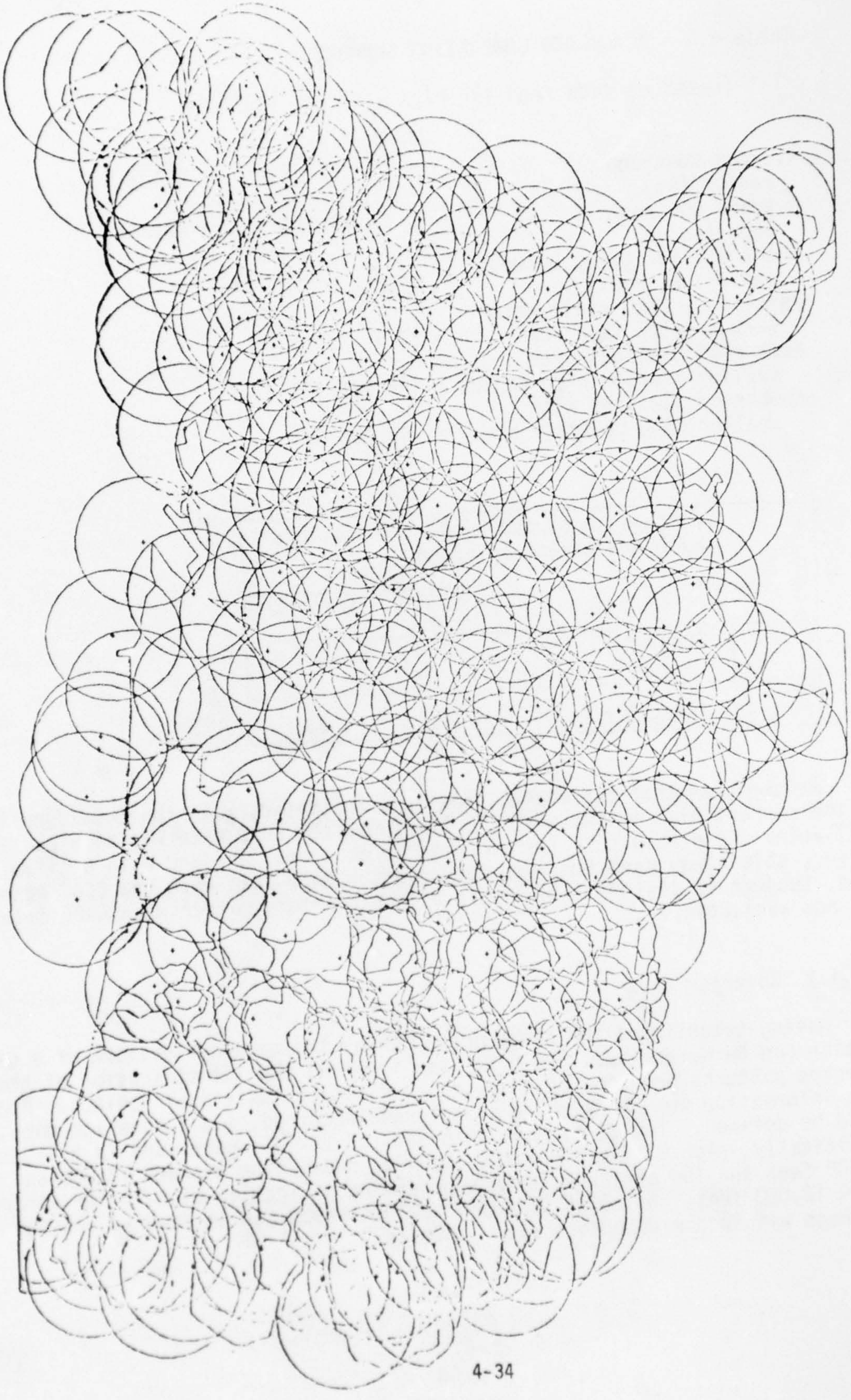


Figure 4.18 High Altitude NAVAID Coverage Patterns
130 nm Radius

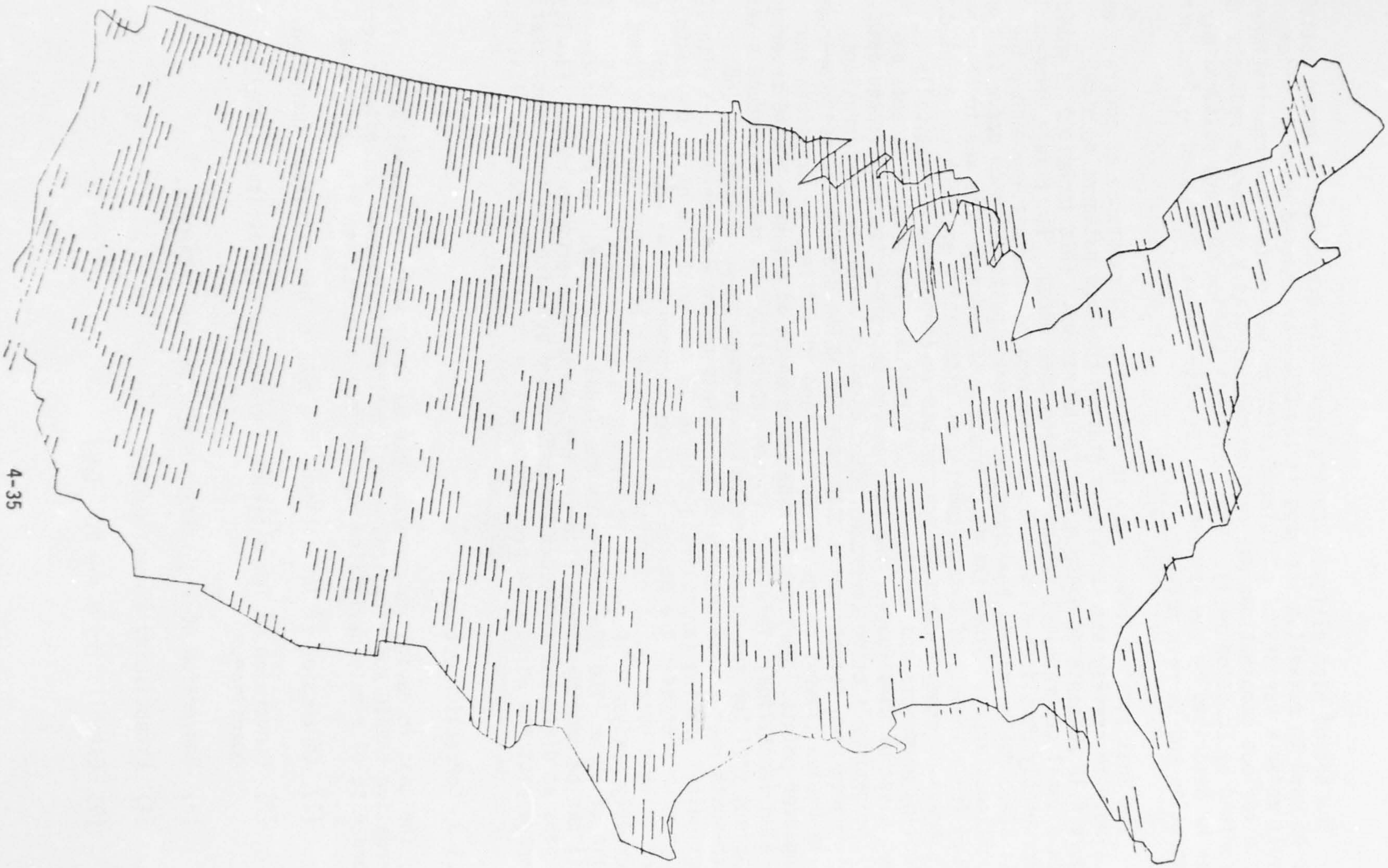


Figure 4.19 Coverage Gaps Based Upon Current High Altitude VORTACs With 50 nm Maximum Coverage Radius (lines represent coverage gaps)

The set of high altitude VORTACs with their associated coverage patterns can be used to establish the gaps in the CONUS or charted coverage which result under a variety of postulated error budget-route width combinations. These various combinations may each be expressed as a "coverage radius", as described by Equation (4.1). The individual station coverage patterns may then be described by the appropriate coverage radius, truncated by frequency protection and terrain effects.

The most straightforward way to determine the existence of coverage gaps is simply to overlay the individual station coverage patterns on a map. Figure 4.18 presents an example for 130 nm radius. This technique is useful when a small geographical region is being considered. It rapidly becomes unreasonably complicated, however, as the area of interest approaches the full CONUS due mainly to the irregular coverage patterns which occur in the mountainous areas. Since the determination of coverage gaps was to be performed for a variety of cases (radii), an alternative approach was adopted. In a previous study a computer program was developed for automatically selecting waypoints and VORTACs for RNAV routes. The program accepts as input a set of RNAV routes, the station and terrain-oriented coverage data and the maximum station coverage radius based on accuracy considerations. The program then selects the NAVAID stations which provide the best coverage of the routes (fewest changeover points) and identifies the waypoints and changeover points. Portions of each route which do not have VORTAC coverage are also identified. This last program capability was used to produce a very efficient tool for the determination of coverage gaps. A total of 168 north-south routes were drawn with end points on the U.S. border and with 20 minutes longitudinal spacing (approximately 13 nm in the north, 18 nm in the south). The program processes the routes in 10 nm increments, the end result of which is that every point associated with a 10 x 15 nm grid over the CONUS is discretely analyzed. Figure 4.18 presents a sample result based on a coverage radius of 50 nm (the minimum radius examined). Coverage plots for different radii can be made by simply altering the appropriate program input. Finally, the gaps at different altitudes are determined by using the individual station coverage patterns which have been processed to reflect the desired altitude.

4.2.1.3 Corrective Options

The gaps in navigation coverage can be dealt with in several ways. Five alternative NAVAID modifications were identified to provide increased coverage in order to eliminate navigation gaps. These alternatives are as follows:

(1) Conversion of low altitude VOR/DMEs to high altitude operation.

(2) Conversion of low altitude VOR/DMEs to high altitude DVOR/DME operation.

(3) Conversion of high altitude VOR/DMEs to DVOR/DMEs.

(4) Establishing a new VOR/DME.

(5) Establishing a new DVOR/DME.

Specific cases (1977 ρ - θ and ρ - ρ) were evaluated at three altitudes, 18,000, 24,000 and 30,000 feet in order to establish the VORTAC requirements and cost sensitivities to minimum altitude restrictions.

The primary emphasis, however, was focused on achieving the desired coverage by converting, upgrading and/or adding facilities to the baseline VORTAC system. An iterative process was used to estimate the most cost-effective set of modifications for a given set of route width-error budget conditions (reflected in the values of initial VOR and improved DVOR coverage radii).

4.2.1.4 Unit Costs

The estimated implementation cost to achieve the desired coverage performance was derived in this analysis by aggregating the projected unit costs associated with each individual VORTAC change or addition. These costs [44] reflect the expected average implementation cost of the designated conversion, addition or upgrading within the CONUS. This approach was selected in preference to the development of site peculiar costs for each installation, an effort which was considered to be beyond the scope of this study. The costs associated with reducing individual station bearing error, θ_G, as recommended by the Task Force for the 1977 period from 1.9° to 1.5° or the 1982 period from 1.5° to 1.0° are believed to be achievable through the use of DVOR if the initial value of 1.5° can be attained by the use of VOR equipment. The unit costs used in this study are presented in Table 4.5, for both the ρ - θ and ρ - ρ elements of this analysis, and discussed in Sections 4.2.2 and 4.2.3, respectively.

4.2.1.5 Frequency Protection

As was previously addressed in Section 4.2.1.1, frequency protection is one of the primary problems associated with the addition of new VOR and/or DME stations. The problem was of such magnitude that the FAA at one time proposed an eventual reduction in the separation for VOR frequencies from 100 to 50 kHz, thereby providing the potential to double the number of available frequencies. The potential for DME communication capabilities were likewise doubled by providing an additional interrogation rate (Y) for each existing channel. Second, frequency protection includes protection not only from those of adjacent frequencies. Thus, while use of the new frequencies will ease the burden of finding a vacant frequency for a given station, both adjacent frequencies will be of the original set and adjacent channel protection, although improved, will remain a problem.

Co-channel frequency protection for a station is based upon two factors; the desired radius of the frequency-protected airspace and its maximum altitude. Protection is assured when there are no stations of the same frequency within the radio horizon distance of any point within the desired frequency-protected space. The region wherein no co-channel stations are allowed is generally defined to be a circle with radius equal to the sum of the frequency protected service area radius and the radio horizon distance at the maximum protected altitude. For high altitude VORTACs, this results in a radius of 390 NMI (130 + 260).

Table 4.5 VORTAC Implementation Unit Costs, 1975 Dollars

New Facilities	
Dual VOR-DME	$279,900
Dual DVOR-DME	$372,000
Dual DME	$154,000
Dual VORTAC	$274,300*
Modification of Existing Facilities	
Convert low altitude VOR-DME to high altitude operations	$7,500
Add DME to VOR (dual)	$86,400
Convert VOR to DVOR (dual)	$160,500

*Since the cost of a new VORTAC installation is nearly the same as a VOR-DME (due to use of existing TACAN equipment) an analysis of VORTAC vs VOR-DME requirements was not attempted.

Adjacent channel frequency protection is based upon totally different considerations. Specifically, the signal from adjacent channel stations cannot exceed that of the desired station by more than 46 dB. For stations of similar power, this relative signal strength is a function of the distances from the aircraft to each of the stations. Figure 4.20 illustrates this relationship. The interference zone is the region wherein the signal strength of the undesired station is expected to exceed the desired station by the previously stated amount. The spacing (S) provides the necessary radius to insure that the interference zone does not intersect the service area. For high altitude VORTACs, the interference zone extends from the undesired station toward the desired station approximately 15 nm (with a margin for error) necessitating a 145 nm spacing. If both stations are close together (specifically radius B, 14 nm, then the signal from the undesired station can never exceed that of the desired. This is the only exception (barring special cases) to the 145 nm adjacent channel spacing requirements for a high altitude VORTAC.

It should be noted that frequency protection in general is not a reciprocal relationship. Station A can be protected from B but not vice versa. This stems from the fact that A is protected from B via consideration of A's service volume but with no consideration of the service volume of B. If the service volume of B is larger than that of A, then B may not be protected. The frequency protected service volume of high altitude stations, however, have both the largest radius and highest altitude of any of the station types (i.e., high, low, terminal, localizer). Thus, the addition of a frequency protected high altitude station will not jeopardize the

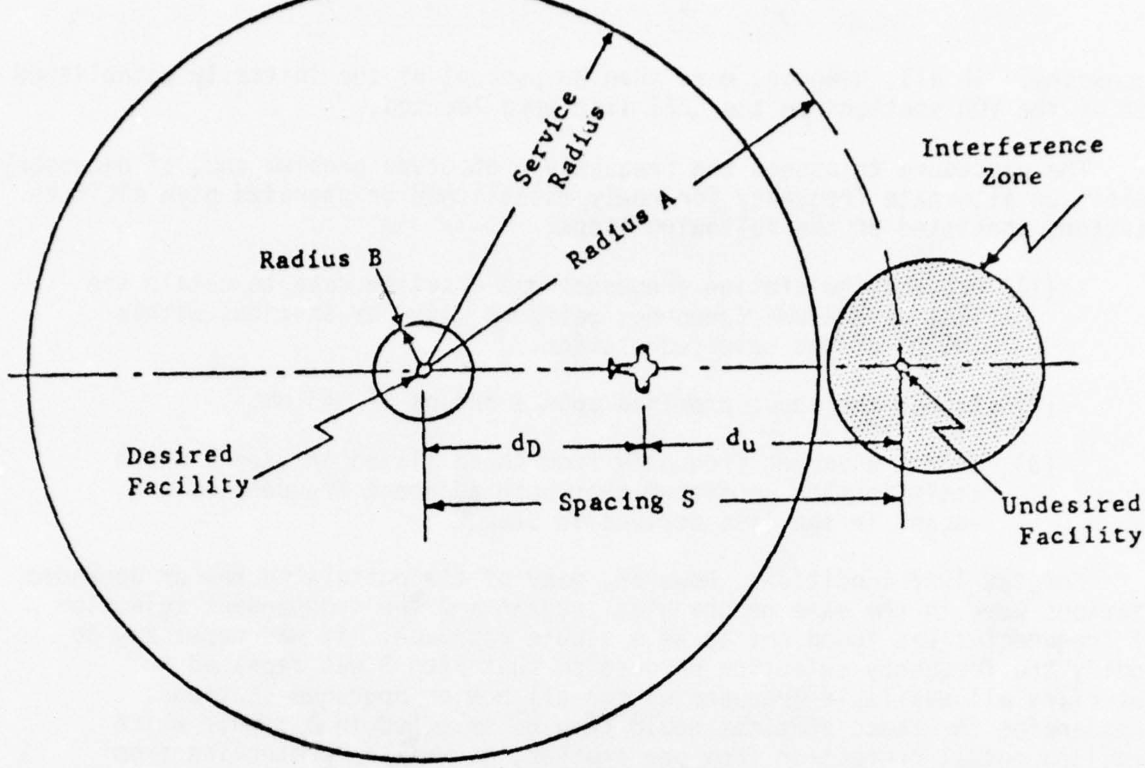


Figure 4.20 Geometry of Adjacent-Channel Interference

protection of any other station unless the other station has a service area which has been extended beyond normal high altitude limits.

This study addressed frequency protection in detail for only one case of interest, the 1977 Task Force recommended route width and navigation accuracy conditions (Table 4.3). Analysis of the frequency protection problems for other situations was beyond the scope of this study. The results are presented in Section 4.2.2.1. The methodology adopted for this effort was constrained to some extent by the available data. The first task, in evaluating frequency protection, consisted of determining the current station frequencies and locations. This necessitated the merging of the frequency data obtained from the current SAFI* listing and station location data which was derived from the FAA NAVAID tape acquired during RNAV studies. This merging effort produced two problems. First, prior processing of the NAVAID tape did not consider localizers. The effect of localizers on the adjacent channel frequency protection of VOR stations could, therefore, not be considered. This problem was minimized by avoiding frequency selection within the localizer region where possible. The second problem was that locations were not found for all stations on the SAFI listing. The vast majority of the missing stations were military, particularly Navy TACANs. Most of these stations are expected to be in coastal regions where the addition of new stations was not found to be

*Semi-Automatic Flight Inspection

necessary. In all, however, more than 90 percent of the initially established set of the VOR stations on the SAFI list were located.

The procedure to assess the frequency protection problem and, if necessary, select an alternate frequency for newly established or upgraded high altitude stations consisted of the following steps:

(1) Process the station frequency and location data to obtain the list of VOR/DME frequency pairs utilized by stations within 390 nm of the selected station.

(2) Repeat the above premised upon a radius of 145 nm.

(3) Select a vacant frequency from those listed in Step 1 which satisfies the condition that both adjacent frequencies are vacant in the list derived in Step 2.

For the 1977 conditions, however, many of the postulated new or upgraded stations were in the same geographical region and the independent selection of frequencies was found not to be a viable approach. It was necessary to modify the frequency selection process so that Step 3 was repeated to determine all available frequencies for all new or upgraded stations. Frequencies for these stations could then be selected in a manner which provided mutual protection from one another, as well as protection from the existing stations.

With regard to high altitude VORTACs, major frequency protection problems would be expected only in the event that a great many new stations are required. However, it is qestionable whether those route width and error budget combinations which would require the addition of many stations will ultimately be implemented. The requirement to add many new VORTACs in an RNAV environment can result only if the usable range of the existing stations are considerably reduced. Furthermore, should it ever become apparent that the addition of many stations will be necessary, long range planning and the shuffling of existing frequencies can in all likelihood provide satisfactory results. Thus, for the aforementioned reasons, specific consideration of frequency protection for other than the 1977 considerations did not appear to be necessary and was therefore not included in this analysis.

4.2.1.6 ρ-ρ Alternatives

For reasons which will be explained, DME/DME navigation, while having certain drawbacks, inherently facilitates very accurate navigation and therefore warrants consideration whenever reduced route width requirements are being addressed. DME/DME navigation, hereafter referred to as ρ-ρ, implies that the aircraft location information is resolved by processing "distance measuring" signals from two non-collocated DME stations. A single DME signal allows an aircraft to ascertain that it is somewhere on a circle surrounding the station with radius equal to the DME reading. Unless the aircraft location is collinear with the stations, the circles defined by

two DME signals will intersect at two points. If the stations are appropriately selected, the two intersection points will be sufficiently separated so that an adequate dead-reckoning system can readily identify the proper intersection.

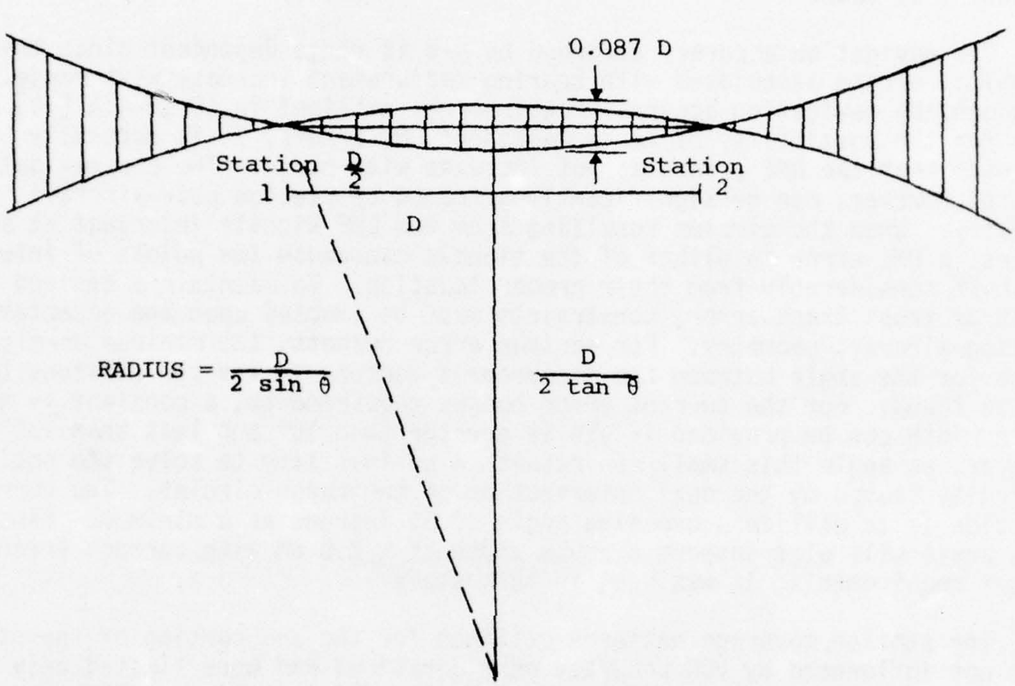
The primary advantage of ρ-ρ is that the range dependent VOR signals are not required. Its disadvantages are that two ground stations are necessary for navigation rather than only one as with the ρ-θ system and specialized ρ-ρ airborne navigation equipment would be required, including a method of position ambiguity solution. These factors tend to compensate for one another, but it is the intent of this study to compare, under a variety of conditions, both ρ-ρ and ρ-θ systems in an RNAV environment in order to assess the relative potential of each.

The navigation accuracy afforded by ρ-θ is range dependent since the geographical errors associated with bearing measurement increase with range. Although the navigation accuracy requirements outlined in AC 90-45A [19] provide for the possibility of range dependent DME errors, it is generally accepted that the DME errors do not increase with range. The ρ-ρ navigation errors, however, can be significantly affected by station pair-aircraft geometry. When the circles resulting from two DME signals intersect at small angles, a DME error in either of the signals can cause the points of intersection to shift considerably from their proper location. To maintain a desired route width or cross track error, constraints must be imposed upon the acceptable station-aircraft geometry. For various error budgets, the minimum permissible value for the angle between the measurement vectors to the two stations ($\Delta\theta$) may be found. For the current error budget requirements, a constant ± 4 nm route width can be provided if $\Delta\theta$ is greater than 10° and less than 170°. However, an angle this small can result in an inability to solve the position ambiguity caused by the dual intersection of the range circles. The current practice is to utilize a crossing angle of 30 degrees as a minimum. Since this angle will also support a route width of $\pm$ 2.5 nm with current error budget requirements, it was used in this study.

The station coverage patterns utilized for the ρ-ρ portion of the study were not influenced by VOR accuracy considerations and were limited only by terrain and frequency protection factors. The determination of the coverage gaps for ρ-ρ navigation is a considerably more difficult process than for ρ-θ navigation. The existence of dual DME coverage from stations satisying the geometrical requirements must be insured for each geographical location (grid point) of concern. Figure 4.21 illustrates the region associated with any pair of stations where coverage is not provided as a result of the $\Delta\theta$ constraint.

The CONUS and charted RNAV coverage gaps for ρ-ρ navigation were determined through the use of a previously developed computer program for ρ-ρ NAVAID selection which was modified for this application. The resulting program was applied to obtain the ρ-ρ results in a manner similar to that of the ρ-θ VORTAC selection program when used to identify ρ-θ coverage gaps. This process is described in Section 4.2.1.2.

COVERAGE IS UNACCEPTABLE IF THE ANGULAR SEPARATION OF THE STATIONS, RELATIVE TO THE AIRCRAFT, IS WITHIN θ DEGREES OF 0 OR 180. PLOT BELOW IS FOR $\theta = 10°$.



- STATION SEPARATION = D
- CURVES GENERATED BY TWO CIRCLES OF RADIUS $\frac{2}{2 \sin \theta}$
- CIRCLE CENTERS AT A DISTANCE OF $\frac{D}{2 \tan \theta}$ FROM MIDPOINT BETWEEN STATIONS

FIGURE 4.21 ρ-ρ COVERAGE LIMITATIONS

Since station coverage distances in excess of 130 nm were not considered, ρ-ρ coverage gaps could be eliminated only by establishing additional high altitude DME stations. For reasons of cost, however, a selection priority system pertaining to the alternatives available for establishing the new stations become apparent. The most cost effective solution stems from the fact that there is no physical or operational difference between low and high altitude DME stations. The "upgrading" of a low altitude VORTAC, or even only the DME portion thereof, consists only of insuring frequency protection and performing a flight inspection. The unit cost of this activity has been estimated by the FAA [44] to be $7500, primarily a flight inspection expense. Two additional corrective options exist, both of which require the use of new, rather than converted, DME equipment. These involve the addition of a DME to an existing VOR station and the installation of DME stations (without VOR) at new sites. The costs of these corrective options are included in Table 4.5.

The only difference between the methodology adopted for the elimination of the ρ-ρ coverage gaps as compared to ρ-θ was that it was necessary to rely more extensively upon the computer program due to the terrain and $\Delta\theta$-induced coverage irregularities. The first step was to establish the current high altitude ρ-ρ gaps. In view of the previously cited costs, the second step was that of identifying all low altitude VORTACs whose upgrading would be expected to either fill or reduce the gaps. These were then added to the high altitude station set and the coverage program rerun. The additional DMEs required for each of the situations addressed were determined by an iterative process of manual selection followed by computer verification. This process was continued until all the gaps in the stipulated coverage areas were filled.

4.2.2 ρ-θ NAVAID System Requirements

The RNAV Task Force recommended error budgets and route widths to be attained in the 1977 and 1982 implementation periods. This section identifies the modifications to the existing ρ-θ NAVAID system that would be required in order to meet these objectives. The associated implementation costs are presented based on the unit costs summarized in Section 4.2.1.4. A means is also provided for the reader to derive implementation costs based on a new set of VORTAC characteristics and costs through use of the cost sensitivity data contained in Section 4.2.2.2.

4.2.2.1 1977 Charted RNAV/CONUS Coverage Requirements

The 1977 error budget and route width requirements, as recommended by the Task Force, are summarized in Table 4.3. The ground VOR error, $\theta_G = 1.5°$, was to have represented an improvement from the assumed current 2 σ value of θ_G, namely 1.9°. This improvement was to be achieved by converting existing VORs (either high or low altitude stations) to high altitude DVORs. Those VORTAC modifications made up two of the five corrective options assumed to be available for use by the VORTAC system planner, as defined in Section 4.2.1.3. An examination of the current set of high altitude VORTACs revealed that the

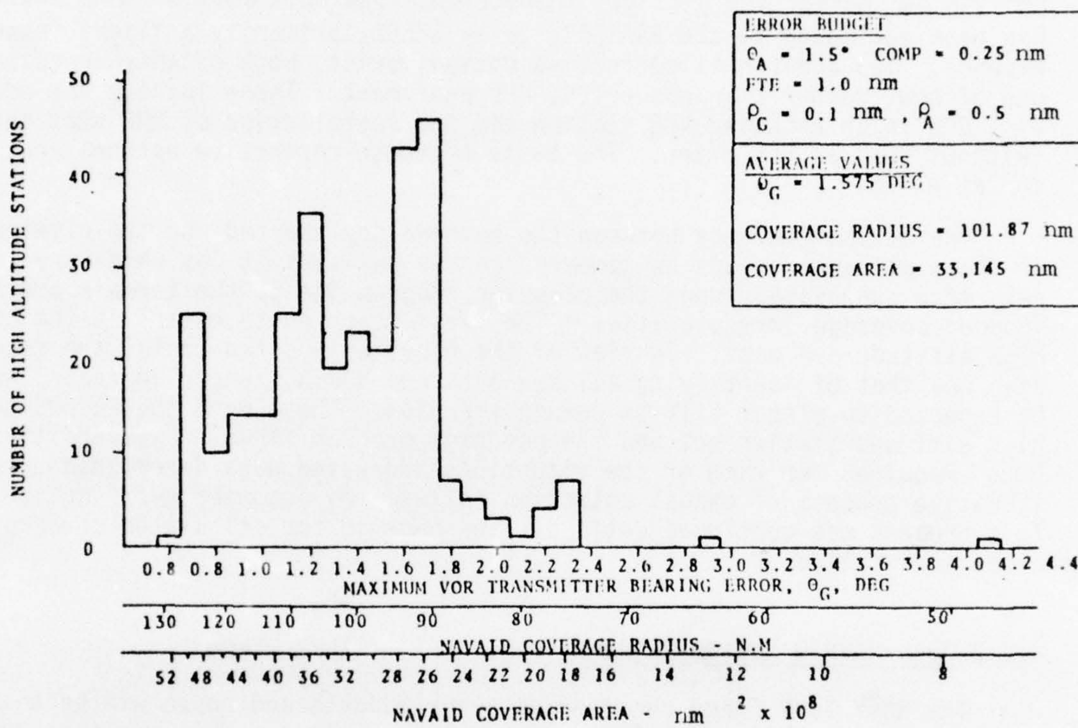


Figure 4.22 Distribution of Current High Altitude Stations As A Function of Maximum Observed Station Bearing Error θ_G (Maximum Route Width - 4 nm)

Table 4.6

SUMMARY OF NAVAID REQUIREMENTS TO SATISFY 1977 TASK FORCE CONDITIONS

REQUIREMENTS FOR COVERAGE OF NAFEC ROUTE STRUCTURE			
FLIGHT LEVEL	180	240	300
NEW STATIONS	NS1 NS2 } 2	NS2 } 1	NS2 } 1
LOW ALT. CONVERTED TO HIGH ALT. OPS	CKW DYR LBF RHI RLG } 5	DYR LBF RHI } 3	DYR LBF RHI } 3
IMPLEMENTATION COST ('75 dollars)	597,300	302,400	302,400

REQUIREMENTS FOR FULL CONUS COVERAGE			
FLIGHT LEVEL	180	240	300
NEW STATIONS	NS1 NS2 NS3 NS4 NS5 NS6 } 6	NS2 NS4 NS5 } 3	NS2 NS4 } 2
LOW ALTITUDE STATIONS CONVERTED TO HIGH ALTITUDE OPERATIONS	BJI BTM CKW CTB DYR ISO ISN LBF LOL MOT MQT MSO PHP RHI RLG SDO } 16	BJI CKW CTB DYR ISO ISN LBF LOL MOT MQT PHP RHI SDO } 13	BJI CKW CTB DNW DYR ISO ISN LBF MOT MQT PHP RHI } 12
VORs UPGRADED TO DVORs	MLP } 1	MLP } 1	MLP } 1
IMPLEMENTATION COST ('75 dollars)	1,959,900	1,097,700	810,300

average maximum* (not 2σ) bearing error was 1.575 degrees, only 0.075 degrees greater than the improved value stipulated by the RNAV Task Force for the 1977 case. This information was extracted from Column 8 of the SAFI VORTAC Systems Characteristic report [45], and was used in the 1977 NAFEC route structure and CONUS coverage analysis. An analysis of CONUS coverage, using 2σ bearing error, which is presented in Section 4.2.2.2, produced similar results.

The SAFI VORTAC System Characteristic data base was used to identify the maximum bearing error for each high altitude VOR station examined in this study. Distribution of this parameter and the associated individual station coverage radius and area is illustrated in Figure 4.22. These values of θ_G were used in combination with line-of-sight limiting terrain factors to identify individual station coverage patterns (Section 4.2.1.1) and to subsequently identify the resulting navigation coverage gaps (Section 4.2.1.2) with respect to either the NAFEC RNAV route structure or full CONUS coverage. Figures 4.23 and 4.24 identify the gaps prevalent in the current VORTAC system at 18,000 feet. Candidate low altitude VOR/DMEs were selected from the set of low altitude VORTACs based on their proximity to the gaps shown in Figures 4.23 and 4.24. The maximum bearing error value was determined for each VORTAC from the SAFI VORTAC Systems Characteristic report and used in combination with the appropriate terrain features to produce the coverage contours shown in Figure 4.25. These contours were then used to identify which of the candidate low altitude stations should be converted to high altitude operations, and an estimate was made of the most cost-effective combination of the five corrective options which would provide the desired coverage.

Table 4.6 summarizes the resulting requirements to provide either RNAV NAFEC route structure (Figure 4.26) or full CONUS coverage at altitudes of 18,000, 24,000 or 30,000 feet, with the symbols of Figures 4.23, 4.24, 4.27 4.28, 4.29 and 4.30 identifying the locations of the recommended VORTAC system modifications. Because of the relatively low values of θ_G, only one station, MLP, was upgraded to a DVOR. In that case its current θ_{GMAX} of 1.9° was assumed to be reduced to a value of 1.5°.

Implementation costs are $597,300 for a charted RNAV structure and $1,959,900 for full CONUS coverage with ± 4 nm route widths and the Task Force 1977 recommended error budget. Although the study did not specifically consider the removal of high altitude VORTACs whose coverage is entirely redundant, it can be seen from Figure 4.18 that considerable redundancy appears to exist. Determination of which stations could be removed will be dependent upon a detailed analysis of coverage requirements for the route structure designed for implementation. The NAFEC structure upon which this analysis was based was designed as an input to these payoff studies and, while representative of the techniques to be employed in the development of an implementation structure, is not an optimum structure which has been coordinated with both low altitude and terminal area designs. Removal of only 12 high altitude VORTACs would provide an annual maintenance cost savings equal to the one-time upgrading cost required for charted RNAV coverage (See Section 4.3).

*based upon a total of 720 observations taken along each 1/2° radial

Figure 4.23 Ground VOR/DME Requirements to Provide NAFEC RNAV Route Structure Coverage, 1977 Conditions at 18,000 Feet

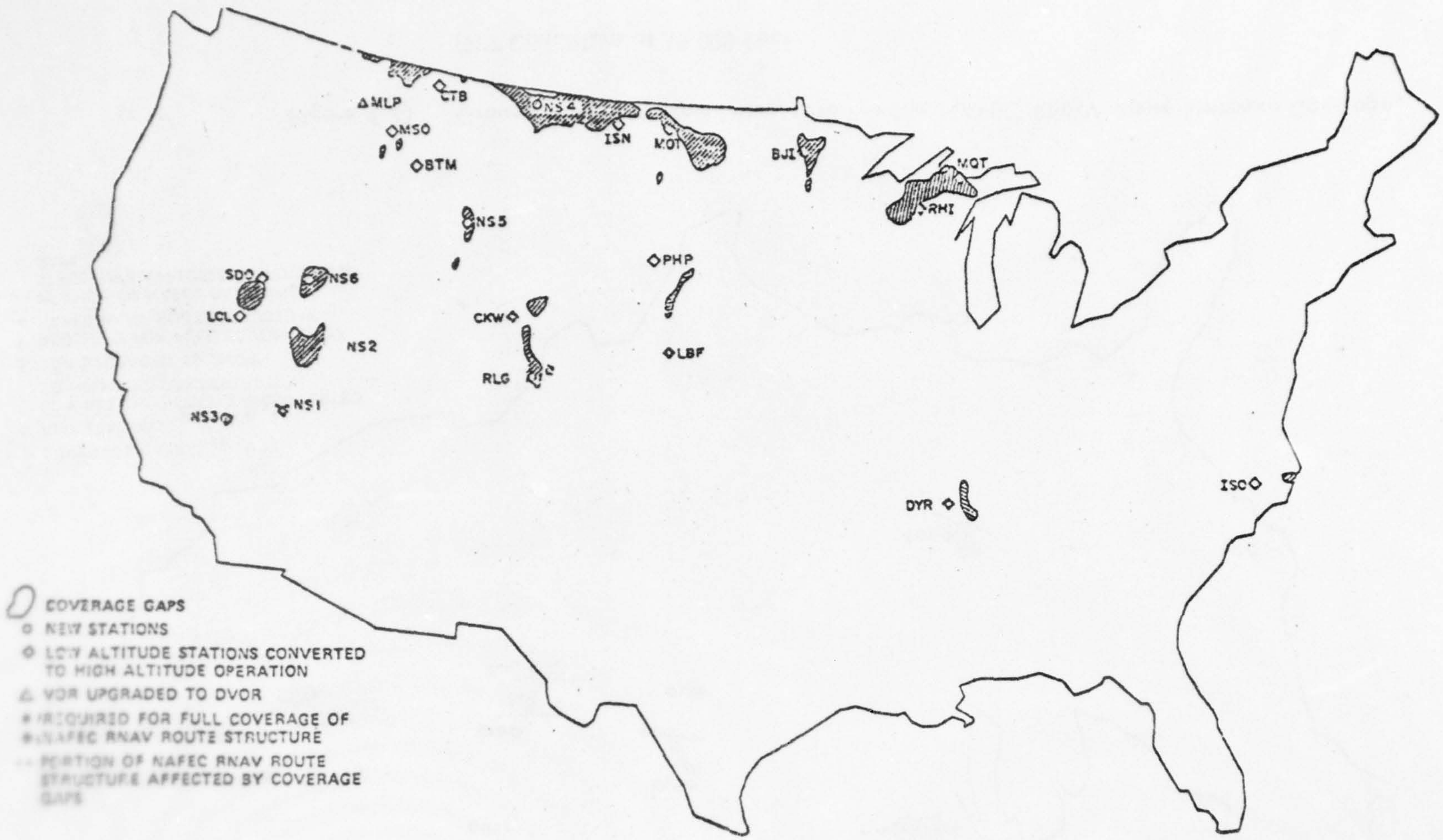


Figure 4.24 Ground VOR/DME Requirements To Provide Full CONUS Route Structure Coverage, 1977 Conditions at 18,000 Feet

AD-A039 225 SYSTEMS CONTROL INC PALO ALTO CALIF F/G 17/7
IMPLEMENTATION OF AREA NAVIGATION IN THE NATIONAL AIRSPACE SYST--ETC(U)
DEC 76 W H CLARK, E H BOLZ, H L SOLOMON DOT-FA72WA-3098
UNCLASSIFIED FAA-RD-76-196 NL

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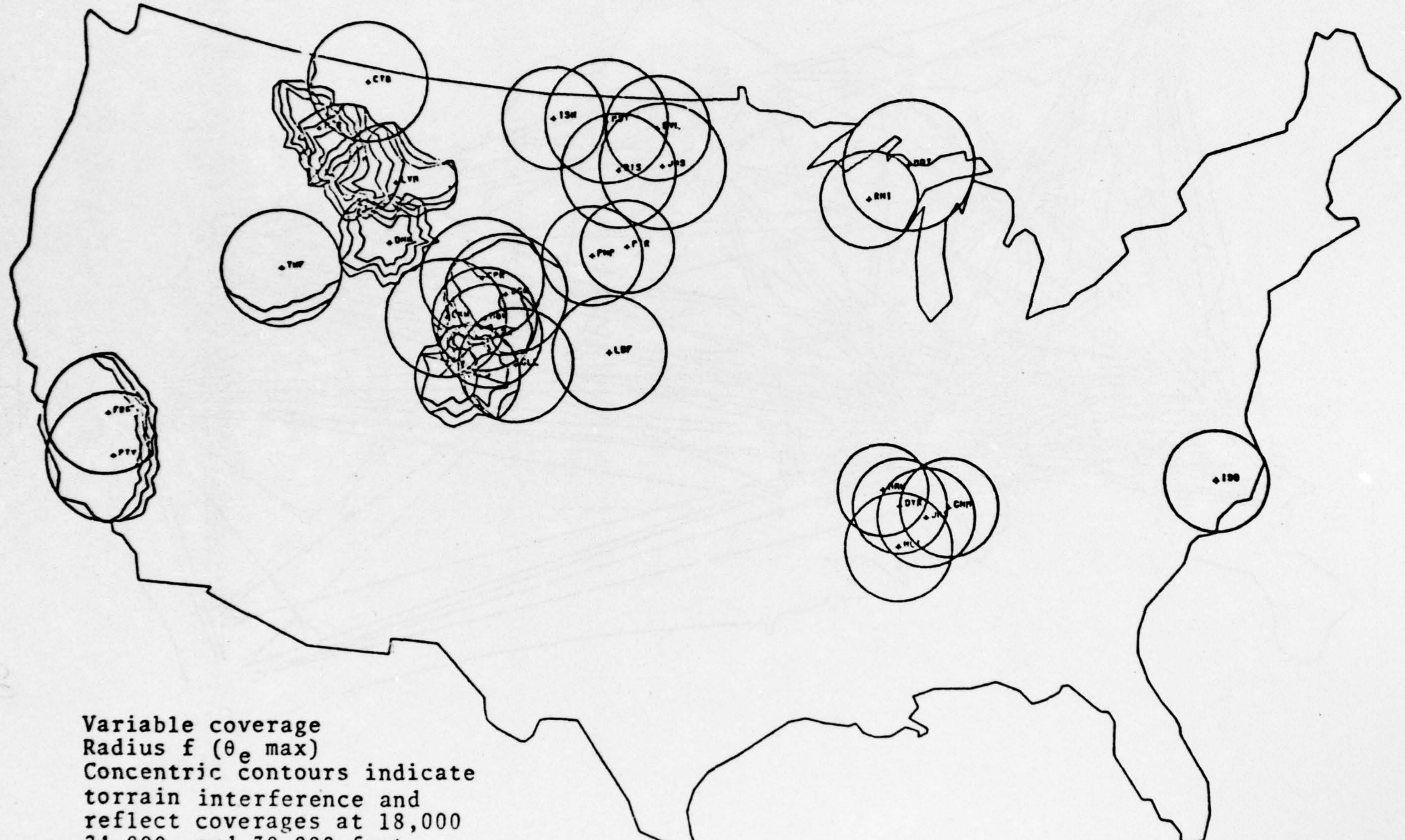
Figure 4.25

LOW ALTITUDE TO HIGH ALTITUDE CONVERSION CANDIDATE NAVAID STATIONS
1977 TASK FORCE CONDITIONS



Variable coverage
Radius f (θ_e max)
Concentric contours indicate
torrain interference and
reflect coverages at 18,000
24,000, and 30,000 feet,
respectively.

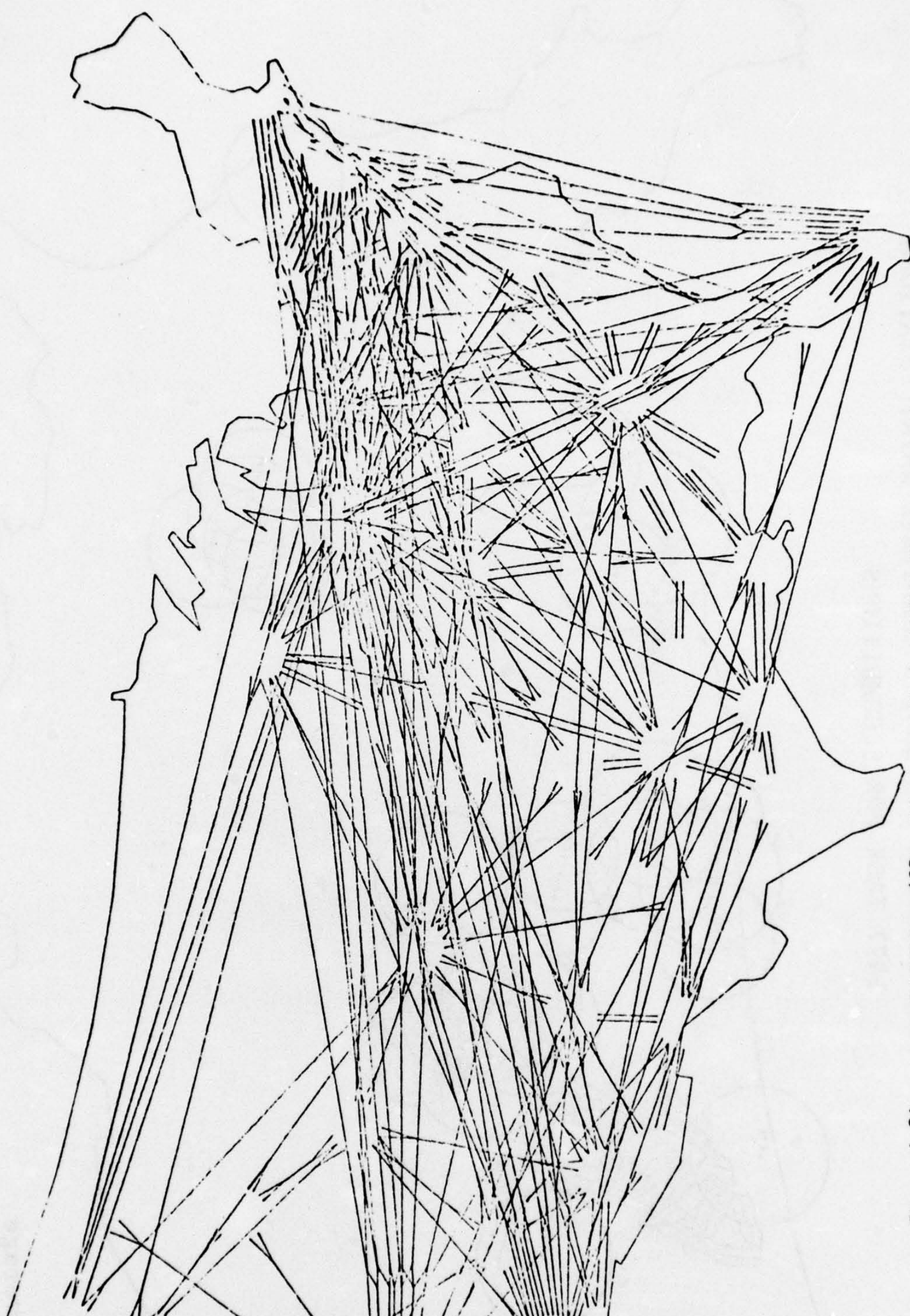


Figure 4.26 NAFEC 429 Airport Pair RNAV Route Structure

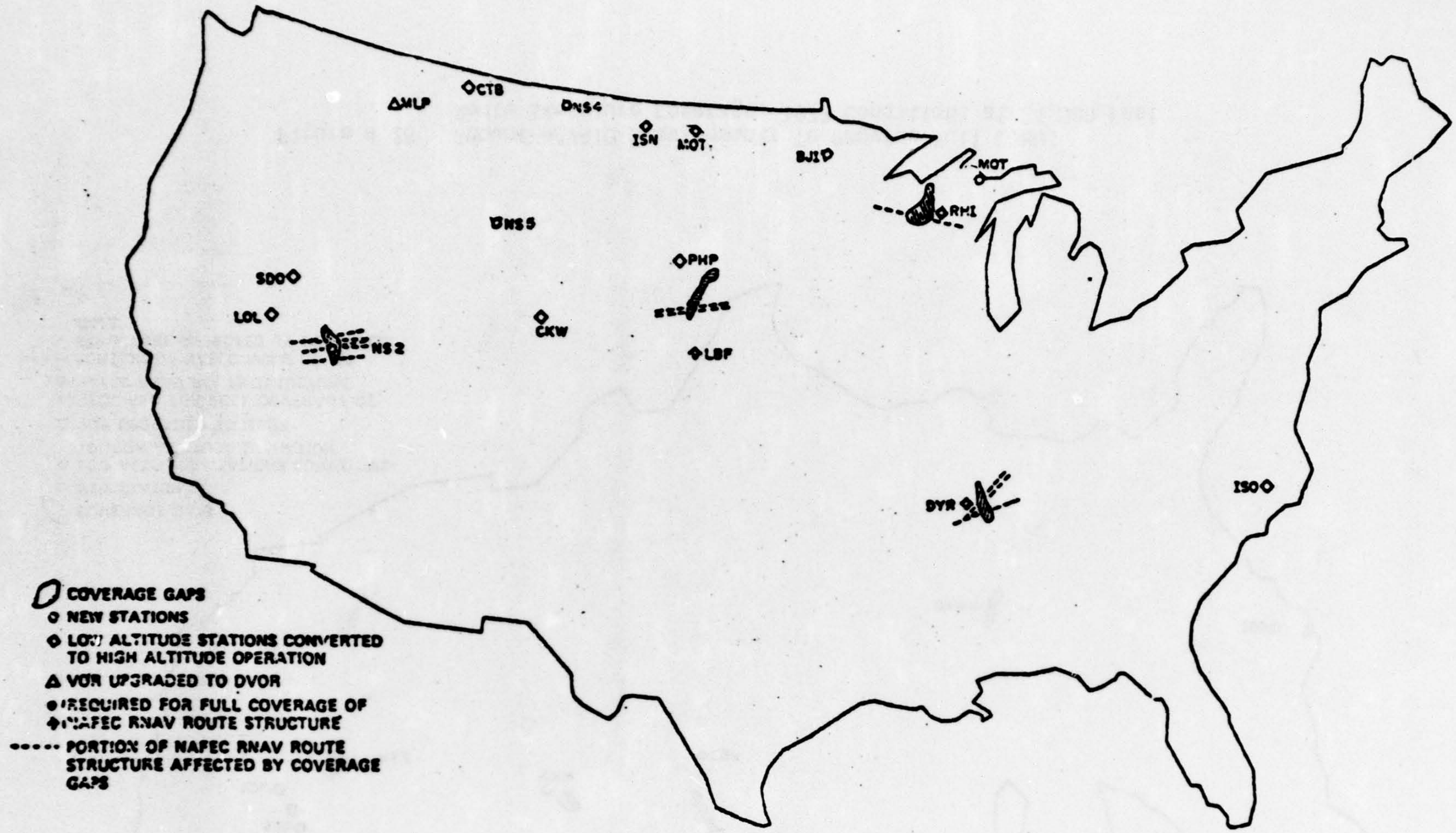


Figure 4.27 Ground NAVAID Requirements To Provide NAFEC RNAV Route Structure Coverage, 1977 Conditions at 24,000 Feet

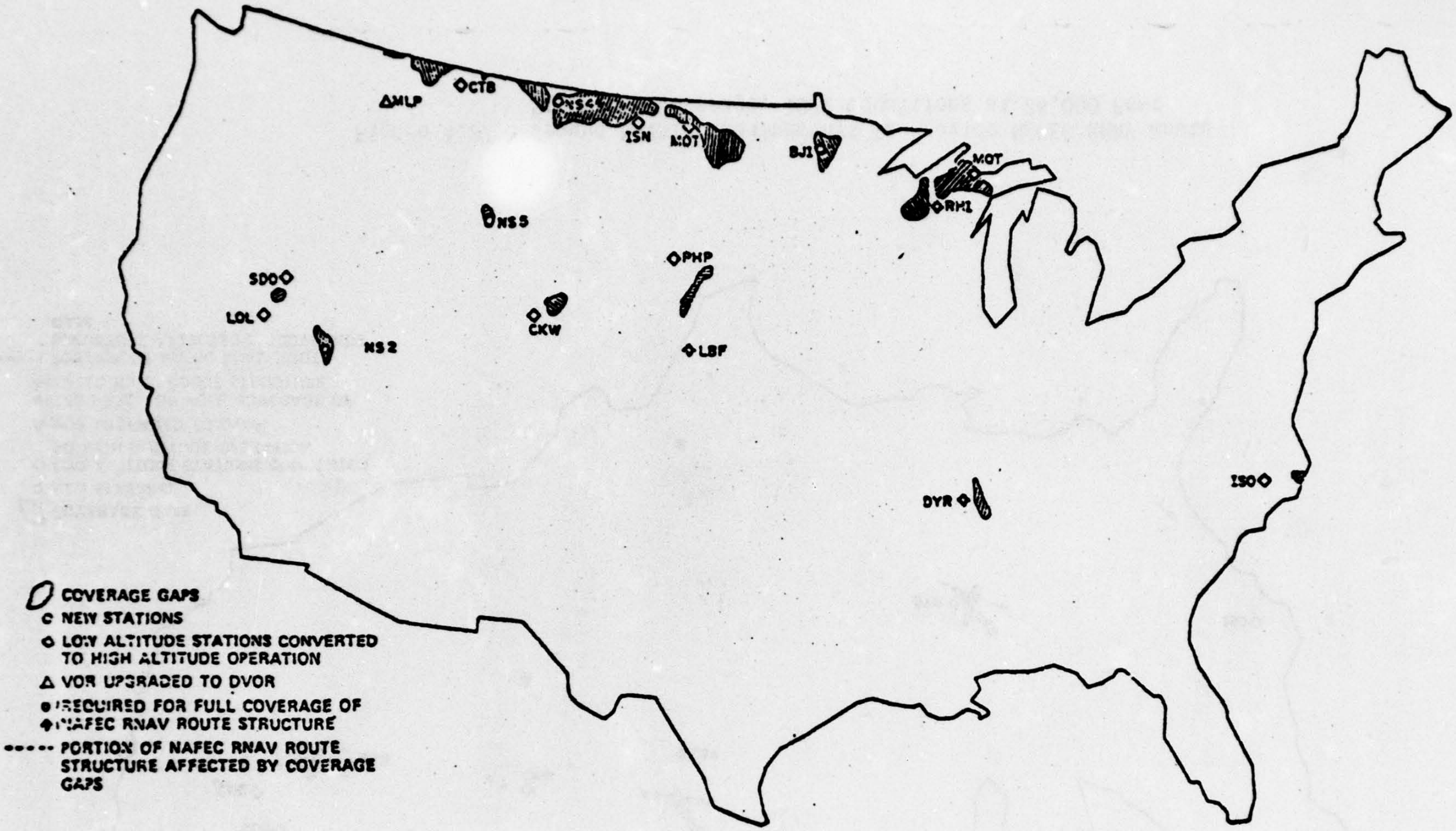


Figure 4.28 Ground NAVAID Requirements To Provide Full CONUS Route Structure Coverage, 1977 Conditions at 24,000 Feet

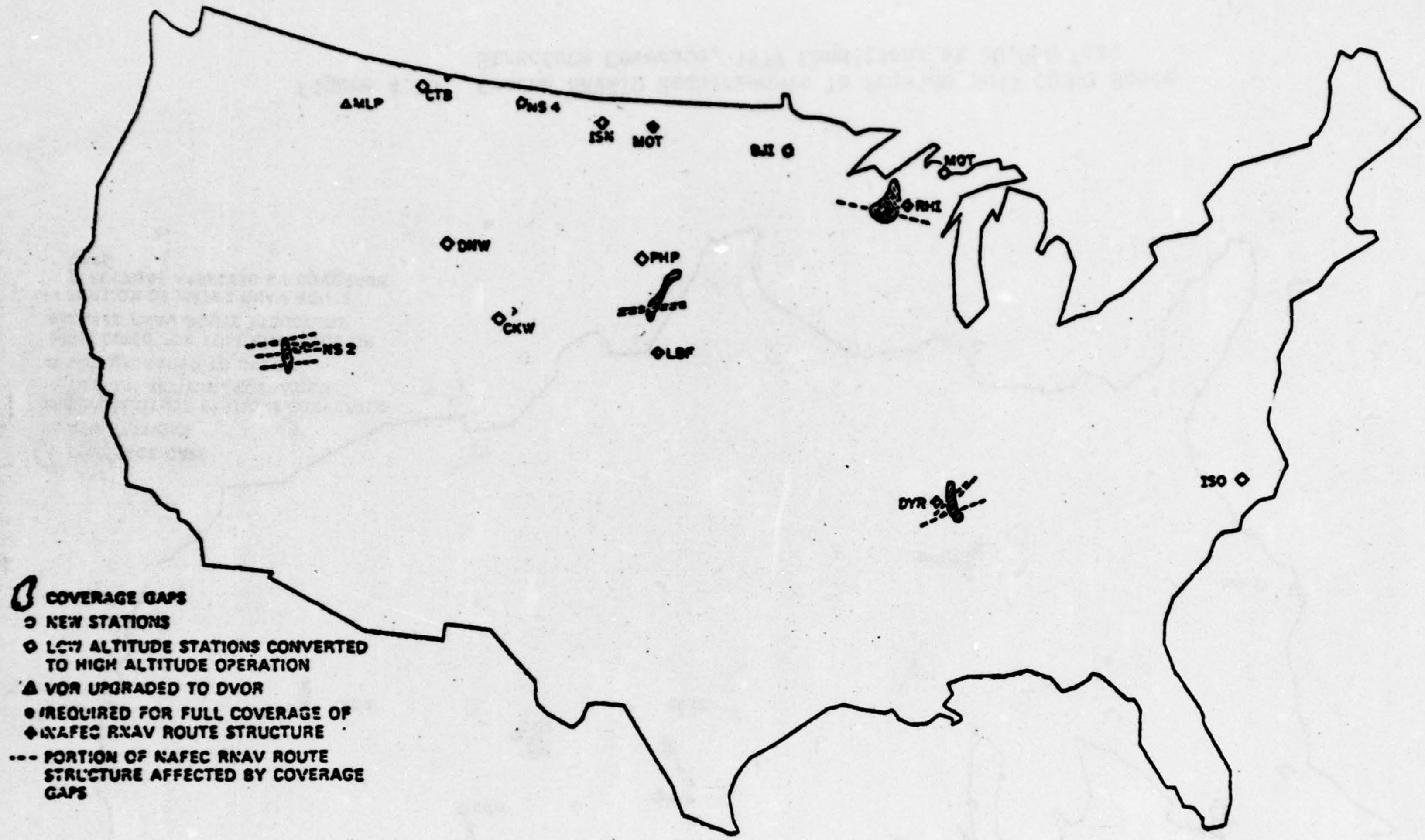


Figure 4.29 Ground NAVAID Requirements To Provide NAFEC RNAV Route Structure Coverage, 1977 Conditions at 30,000 Feet

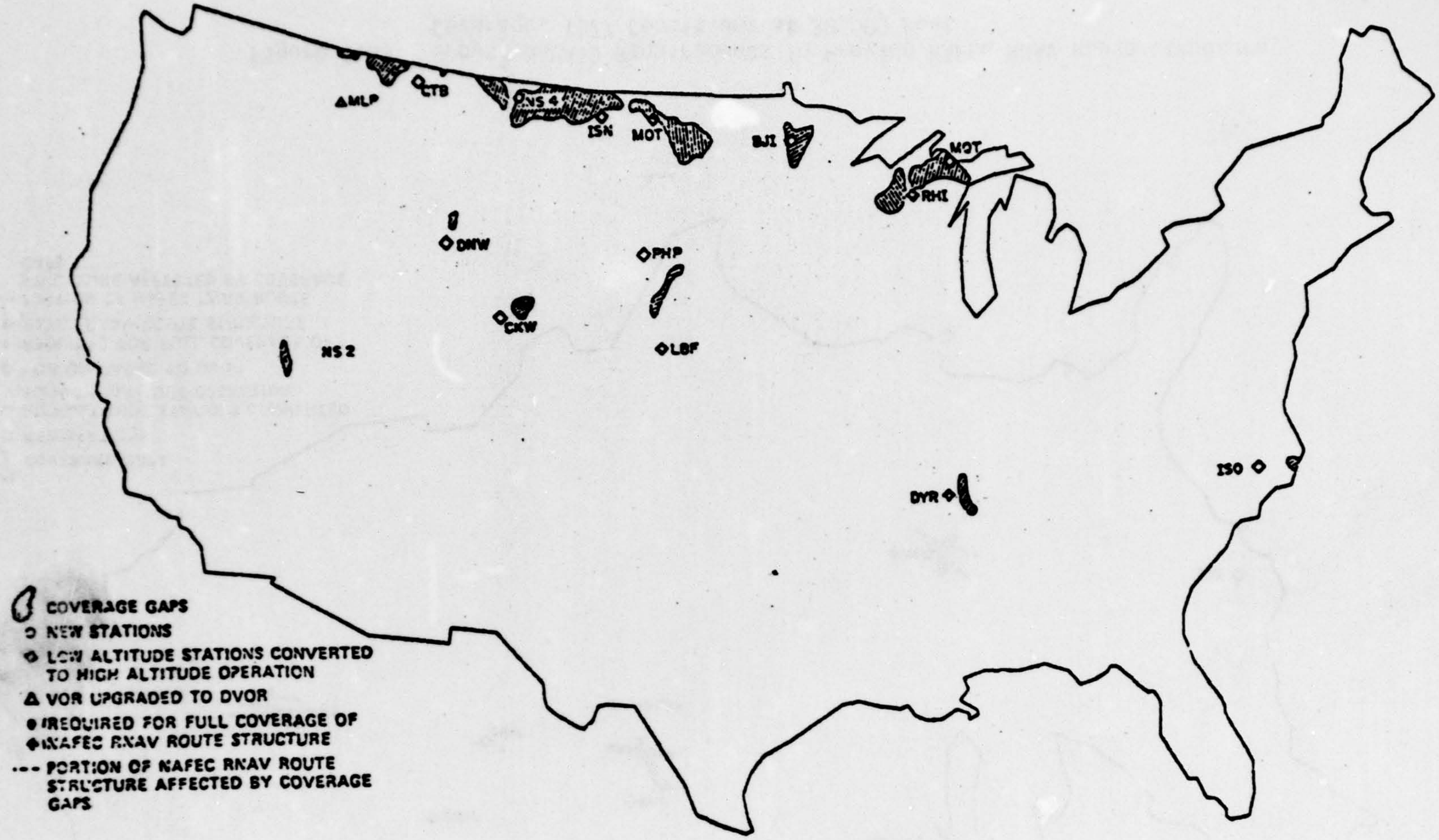


Figure 4.30 Ground NAVAID Requirements To Provide Full CONUS Route Structure Coverage, 1977 Conditions at 30,000 Feet

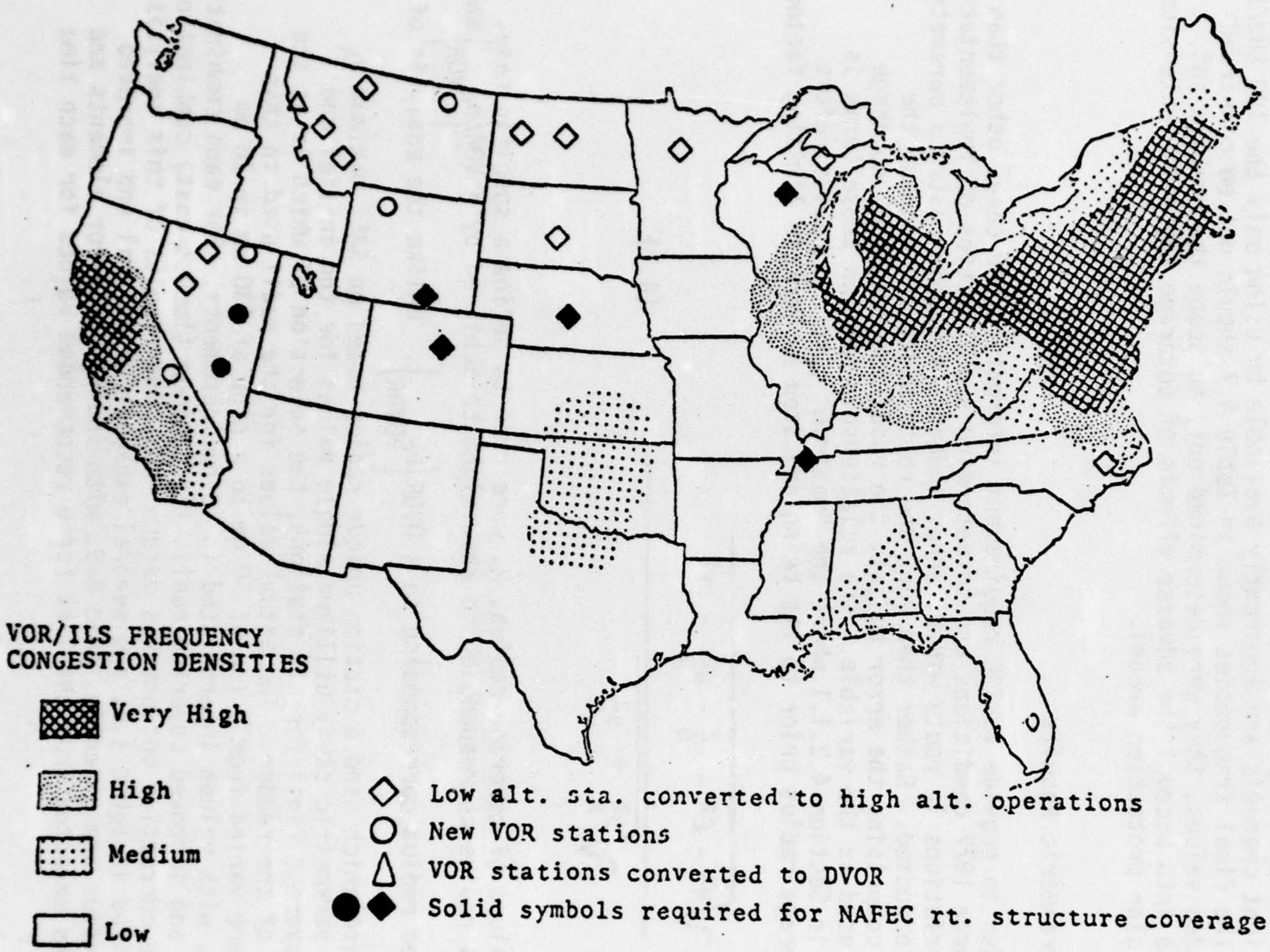


Figure 4.31 1977 VORTAC Requirement Impact on Frequency Congestion

The locations of the modified stations would appear to minimize the problems that might be associated with frequency protection. When these locations are superimposed on a frequency congestion map (Figure 4.31), approximating the regions of frequency congestion, all relevant stations appeared to be located in the low density regions. Since this map was only an approximation of the actual conditions presented in Reference 4, a more rigorous approach, as described in Section 4.2.1.5, was employed. The results of this activity are presented in Table 4.7. These results indicate that sufficient channels are apparently available by using only the 100 kHz/X channels. The final frequencies shown in Table 4.7 should not be construed as recommended values, they were determined only to scope the problem and did not take into account the adverse effects of coverage keyholes (extensions out of circular protection areas).

4.2.2.2 Parametric Results

In order to provide VORTAC requirement information for cases other than the Task Force 1977 conditions and to determine sensitivities of implementation costs to variations in route width, error budgets, and unit costs, a parametric study was conducted. Rather than vary the route width and each of the parameters comprising the error budget, the resulting "maximum" coverage radius was used as the variable. The relationship between these terms is identified in Section 4.2.1.1 where the "maximum" coverage radius refers to the coverage radius prior to its being adjusted by terrain limiting factors:

$$R = \frac{\sqrt{W^2 - C^2 - \rho_G^2 - \rho_A^2 - F^2}}{\sqrt{\theta_A^2 + \theta_G^2}} \qquad (4.1)$$

Two values of coverage radius, R, were used to define a specific case, the initial radius corresponding to what might be achieved by a VOR $\left(\theta_{G_{VOR}}\right)$ and the improved radius corresponding to a DVOR $\left(\theta_{G_{DVOR}}\right)$. Unlike the analysis of the 1977 case which used a station unique radius based on SAFI maximum θ_A data, this parametric study utilized single values for the initial and improved coverage radii for all stations, the selection of which is at the discretion of the reader. The actual values for the radii used in this analysis were varied from a low of 50 nm to a high of 130 nm in 20 nm increments, with values interpolated in 10 nm increments. For each combination of initial and improved coverage radii, the optimum (lowest cost) combination of the five corrective options was determined. The results of this analysis are summarized in Table 4.8, and several examples of initial and improved coverage radius are given in Table 4.9, with individual error elements and route widths selected from the Task Force recommended values for each time period.

The sensitivity of the implementation costs identified in Table 4.8 with respect to initial and improved radius is illustrated in the plot of Figure 4.32. The range of coverage radii examined produced a three order of magnitude variation of the implementation costs required to achieve full coverage at 18,000 feet.

Additional implementation cost sensitivities with respect to the parameters of route width and flight technical error, for discrete sets of error budgets, were derived by computing the corresponding initial and improved coverage radius, locating the appropriate intersection on Figure 4.32 and reading the corresponding implementation cost. These sensitivity results are presented in Appendix F.

In the event it is desired to modify one or more of the unit costs presented in Section 4.2.1.4, it is necessary to have knowledge of the number of each type of corrective option that would be required, for specified combinations of initial and improved radii, in order to recompute total implementation costs. Figures presenting this information, based on the data presented in Table 4.8, for each of the five corrective options employed in this study are also included in Appendix F.

The cost to provide CONUS coverage for 1977 conditions may be computed from the parametric relationship using the initial and improved radii given in Example C of Table 4.9. In this example it is assumed that the ground DME and airborne equipment error budget has been achieved, and that the improved radius is due to an improvement in ground VOR accuracy from 1.9° to 1.5°. The coverage cost, which is plotted on Figure 4.32, is approximately $1.9 million which is consistent with the cost of $1,959,900 derived in Section 4.2.2.1.

4.2.2.3 1982 CONUS Coverage Requirements

The parametric study was used to estimate the requirements and costs to implement full CONUS coverage at 18,000 feet under the conditions stipulated by the RNAV Task Force for the 1982 period (charted RNAV in 1982 was not recommended by the Task Force). The initial and improved radii corresponding to those conditions are 71.9 and 91.6 nm, respectively (Column H in Table 4.9). The results subsequently presented in this section are based on an initial and final radius of 70 and 90 nm, respectively, and are therefore slightly conservative. The final modifications are summarized in Table 4.10. A total of $6,604,000 would be required to implement the 1982 system directly from the current system.

4.2.3 ρ-ρ Coverage Requirements

Coverage requirements for $\rho - \rho$ (DME-DME) navigation were analyzed for both the 1977 and 1982 route widths and error budgets. A separate analysis for each was not required since ρ-ρ accuracies are such that the error budget which will support ±4 nm route widths will also support ±2.5 nm route widths (see Section 4.2.1.6).

Sets of DME/DME (ρ-ρ) VORTAC System requirements and associated implementation costs were identified so as to provide coverage for the NAFEC RNAV route structure and/or full CONUS coverage, at each of three altitudes, FL180, FL240 and FL300. The first step in this process was to determine the coverage gaps associated with each of these cases based upon the use of the current set of high altitude VORTACs. These results are shown in Figures 4.33, 4.34 and 4.35. It can be seen that virtually full ρ-ρ coverage is already available throughout the eastern and central portions of the country. The mountainous regions, however, present a major coverage problem. As a result of the dual coverage requirements, terrain influences, and the $\Delta\theta$ limitation, many coverage gaps exist. These are reduced markedly, however, at higher altitudes, with the most significant improvement occurring between FL180 and FL240.

The remainder of the ρ-ρ study involved the iterative procedure of manually selecting new or upgraded stations which appeared to offer the potential of eliminating the coverage gaps and then subsequently testing these selections by executing the ρ-ρ coverage program. The procedure required up to four iterations because the program frequently revealed that gaps which were thought to have been covered still remained due to terrain or $\Delta\theta$ influences. Previously added stations were then removed, new ones added, and the process repeated.

At the conclusion of this process, DME requirements and the associated costs for the six situations addressed were identified and are summarized in Table 4.11.

For each situation, the emphasis was placed upon the upgrading of existing VORTAC stations. In fact, virtually all low altitude VORTACs within range of the coverage gaps were utilized. Their aggregate value in the reduction of the gaps was highly significant. There was only a minor difference between the station requirements for coverage at FL240 and FL300. The additional gaps at FL240 as compared to FL300 can be covered for the most part by the upgrading of VORTACs. Filling the gaps at FL240, however, virtually exhausted the capability to upgrade low altitude VORTACs and to add DMEs at VOR sites. Thus, a significant number of new stations were required to provide coverage at FL180. As a result, the associated costs are increased by 150 to 200 percent.

TABLE 4.7

FREQUENCY PROTECTION RESULTS 1977 CONDITIONS

Station ID	Current Frequencies		Type of Frequency Protection Violation	Example Final Frequencies	
	VOR	DME		VOR	DME
BTM	111.6	53	1	117.5	122
CKW	112.2	59	1	115.0	97
CTB	114.4	91	None	114.4	91
DYR	116.8	115	1	117.2	119
ISN	116.3	110	1	113.3	80
ISO	109.6	33	1	108.0	17
LBF	117.4	121	1	115.7	104
LOL	116.5	112	1	117.0	117
MLP	117.8	125	1	115.9	106
MOT	117.1	118	2	117.7	124
MQT	109.0	27	1	114.1	88
MSO	112.8	75	2	112.4	71
PHP	108.4	21	1	117.9	126
RHI	109.2	29	1	113.6	83
RLG	113.8	85	1	115.4	101
SDO	114.3	90	1	112.7	74
NS1				111.2	49
NS2				113.9	86
NS3				113.8	85
NS4				114.7	94
NS5				116.7	114
NS6				113.1	78

1: Frequency change necessary in order to upgrade station.

2: Frequency change necessary to provide vacant frequencies for the upgrading and/or addition of other stations.

TABLE 4.8

SUMMARY OF PARAMETRIC RESULTS
GROUND NAVAID REQUIREMENTS TO PROVIDE FULL CONUS
COVERAGE AT 18,000 FT.

		No.of Low Alt.Sta's Converted to High Alt. Ops With		No.of High Alt.Sta.'s Upgraded To	No.of New Sta.'s Added With		Implementation Costs $(000)
		STD.VOR	DVOR	DVOR	STD.VOR	DVOR	
Unit Costs -$		7,500	168,000	160,500	279,900	372,000	
Initial Radius N. Mi.	Improved Radius N. Mi.						
130	N.A.	6			0		45
110	130	10	0	1	1	0	515
110	N.A.	10			2		635
90	130	26	2	4	2	0	1,733
90	110	27	3	2	2	1	1,960(1)
90	N.A.	24			9		2,699
70	130	64	5	15	1	1	4,380
70	110	75	6	13	4	2	5,521
70	90	75	7	10	5	5	6,604(2)
70	N.A.	77			32		9,534
50	130	84	18	37	0	1	9,965
50	110	103	30	34	0	2	12,014
50	90	132	40	48	0	9	18,762
50	70	173	21	53	19	37	32,414
50	N.A.	203			188		54,144

(1) 1977 full CONUS Coverage.
(2) 1982 full CONUS Coverage.

Table 4.9 Coverage Radii

Task Force Recommended Route Widths and Error Budgets

	1972	1977 (1)	1982(2)
Route Width - W (nm)	± 4 + splay	± 4	± 2.5
Computer Error - C (nm)	0.5	0.25	0.25
Ground DME Error - ρ_G (nm)	0.1	0.1	0.1
Airborne DME Error - ρ_G (nm)	0.5 or 3%	0.5	0.25
Flight Technical Error - F(nm)	2.0	1.0	1.0
Airborne VOR Error - θ_A (deg)	3.0	1.5	1.0
Ground VOR Error - θ_G (deg)	1.9	1.5	1.0
Coverage Radius - R	54.7	103.5	91.6

Examples of Coverage Radii

	A		B		C (1)		D		E		F		G		H (2)	
	Initial	Improved	Initial	Improved	Initial	Improved	Initial	Improved	Initial	Improved	Initial	Improved	Initial	Improved	Initial	Improved
W	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.5	2.5	2.5	2.5
C	.5	.5	.5	.5	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25
ρ_G	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
ρ_A	.5	.5	.5	.5	.5	.5	.5	.5	.25	.25	.25	.25	.25	.25	.25	.25
F	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
θ_A	3.0	3.0	3.0	3.0	1.5	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
θ_G	1.9	1.5	1.9	1.0	1.9	1.5	1.9	1.0	1.9	1.0	1.5	1.0	1.9	1.0	1.5	1.0
R	54.7	57.9	54.7	61.4	90.7	103.5	90.7	121.8	102.9	130.0*	122.5	130.0*	60.4	91.6	71.9	91.6

* frequency protection limit

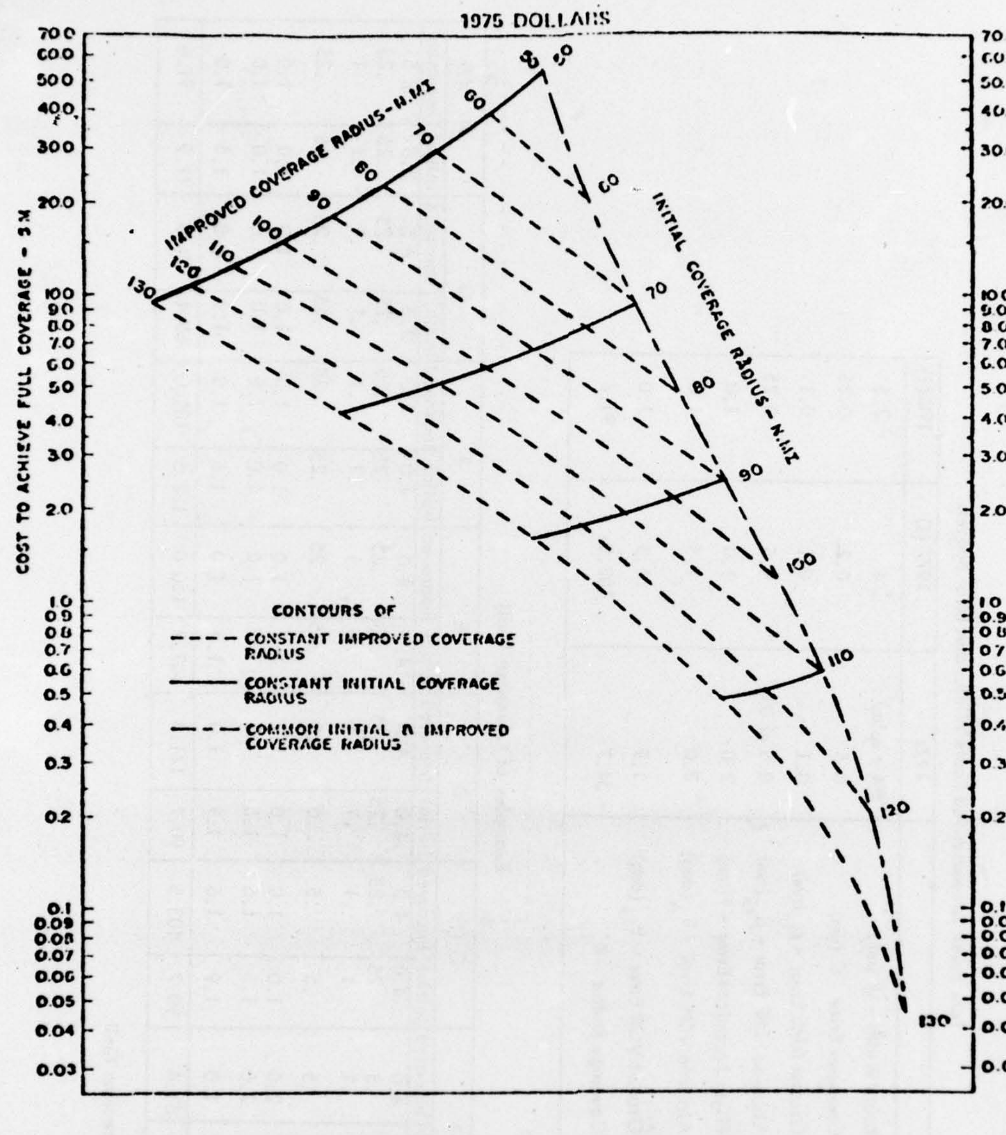


Figure 4.32 Non-Recurring Ground Station System Costs Required to Provide Full CONUS Coverage at 18,000 Feet

TABLE 4.10

SUMMARY OF VORTAC REQUIREMENTS TO PROVIDE
FULL CONUS COVERAGE AT FL 180 IN
ACCORDANCE WITH 1982 TASK FORCE CONDITIONS

NEW VOR STATIONS (5)	NEW DVOR STATIONS (5)
001	002
003	004
007	005
009	006
010	008

HIGH ALTITUDE VOR STATIONS UPGRADED TO DVOR (10)				
DPR	GEG	LRD	MYL	RNO
FST	IMB	MLT	PHX	TBC

LOW ALTITUDE VOR STATIONS UPGRADED TO HIGH ALTITUDE OPERATIONS (75)							
ACH	COT	DMN	FSP	LBB	MMM	RLG	TBE
APN	CPR	DVL	HLV	LEB	MON	RSG	TKO
ATY	CTB	EAU	HMV	LFT	MOT	SDO	TWF
AXN	CTY	ECB	HON	LMT	MOT	SEG	TXC
BIS	CVG	EKN	HRS	LOZ	MSL	SFL	UBS
BJI	DDC	EMP	ISN	LVM	MTA	SHR	
BKE	DGW	FJS	IWD	MAF	PGO	SLR	
CHD	DHN	FLP	JKS	MAP	PIR	SUX	
CNG	DHT	FMY	JMS	MLC	ROM	SWL	
COS	DLL	FOT	LAR	MLU	RHI	TAS	

LOW ALTITUDE VOR STATIONS UPGRADED TO HIGH ALTITUDE DVOR OPERATIONS (7)			
DNW	HIB	MSO	TPH
FBR	ISO	PTV	

IMPLEMENTATION COSTS (in dollars)	$6,604,000

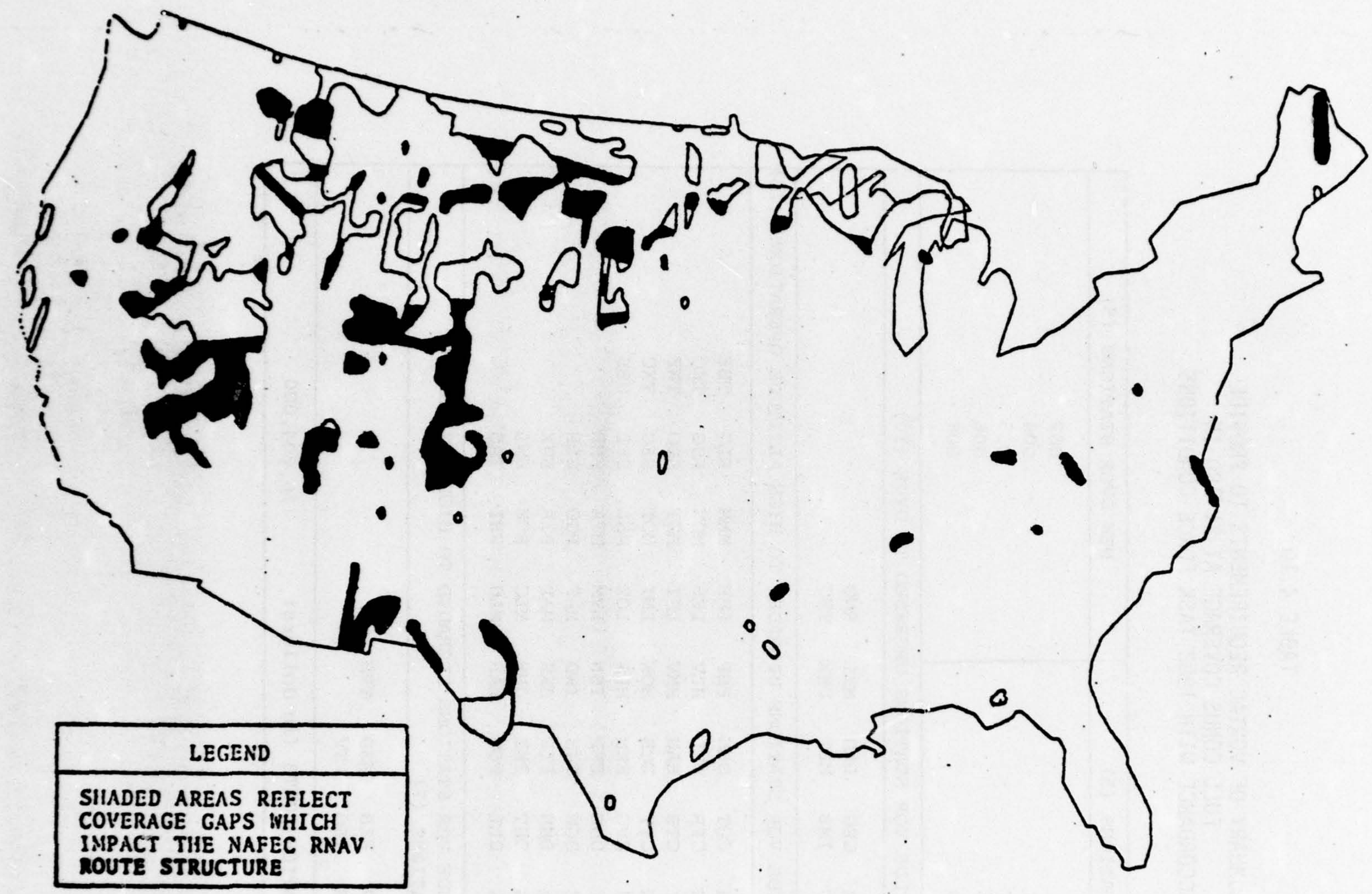


Figure 4.33 ρ-ρ Coverage Gaps at FL180 Considering Current High Altitude VORTACs Only ($\Delta\theta = 30^o$)

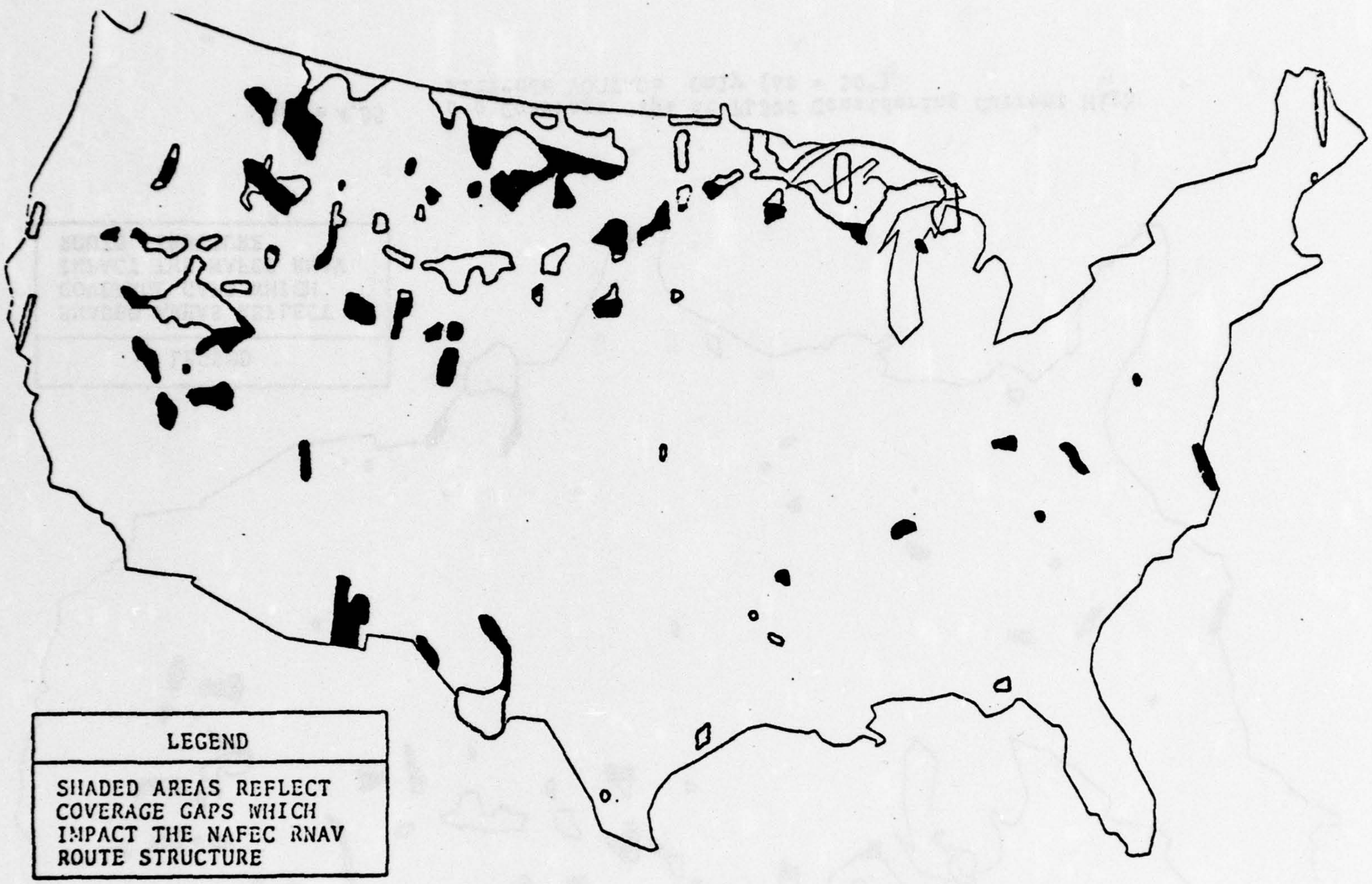


Figure 4.34 ρ-ρ Coverage Gaps at FL240 Considering Current High Altitude VORTACs Only ($\Delta\ \theta = 30^{\circ}$)

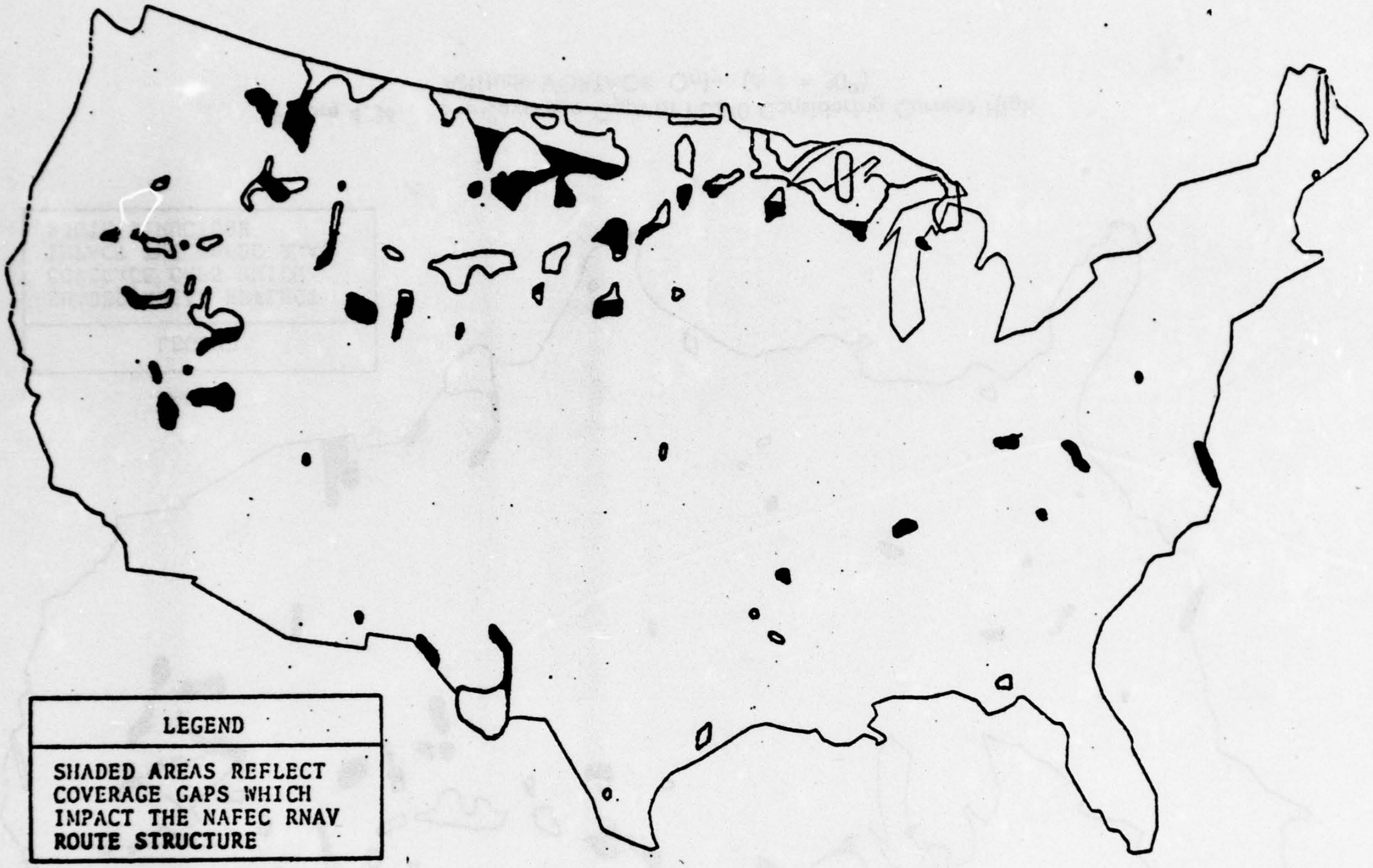


Figure 4.35 ρ-ρ Coverage Gaps at FL300 Considering Current High Altitude VORTACs Only ($\Delta\theta = 30°$)

TABLE 4.11 ρ-ρ NAVAID SYSTEM REQUIREMENTS

Coverage Gap Corrective Options	CONUS						NAFEC RNAV Route Structure					
	FL180		FL240		FL300		FL180		FL240		FL300	
	No.	Total Cost ($000)	No.	Total Cost ($000)	No.	Total Cost ($000)	No.	Total Cost ($000)	No.	Total Cost ($000)	No.	Total Cost ($000)
Convert low altitude VOR-DMEs or VORTACs to high altitude oper.	51	383	50	375	42	315	41	308	36	270	28	210
Add DMEs to low altitude VOR sites	11	950	9	778	9	778	9	778	9	778	7	605
Add new DME sites	29	4466	8	1232	8	1232	27	4158	6	924	6	924
TOTAL		5799		2385		2325		5244		1972		1739

4.3 TERMINAL AREA VORTAC REQUIREMENTS

This section presents the results of a detailed analysis of the effect of Area Navigation, implemented as envisioned by the RNAV Task Force [1], on the requirement for VORTAC stations and their improvements according to the needs of terminal area operations. The basic approach taken in this study has been to investigate four individual terminal areas (Denver, Philadelphia, New York, Chicago) with the primary intent being to eliminate as many existing VORTAC or VOR/DME stations as possible, while providing all services presently provided and meeting the accuracy and coverage requirements outlined by the Task Force for the 1977 and 1982 time periods. The considerations which were observed included high altitude coverage, low altitude coverage, terminal route coverage, route widths and accuracies according to the Task Force, uncompensated slant range error, DME saturation potential, VORTAC requirements for a continued VOR-oriented system, and existing VOR approach procedures. The resulting savings in VORTAC installations are evaluated in terms of savings in maintenance costs and in terms of potential savings in providing low altitude enroute coverage in other areas through station relocation. Other cost savings areas, such as the real estate which could be disposed of, is recognized. The results so determined are extrapolated over all of the high and medium density terminal areas.

4.3.1 Methodology

Each terminal area was studied individually, although because of their close proximity the Philadelphia and New York cases did interact. At each terminal a chart was drawn which shows the major airports and the forty-five mile terminal area boundary (forty-seven at New York). All airports for which instrument approach procedures exist within the terminal area were identified on the chart. All VORTAC and VOR/DME stations (low and high) within the area and within forty miles (frequency protection limit) of the boundary of the terminal area were also identified and on the chart. These charts formed the basis for the VORTAC requirements analysis, and are presented in Figures 4.36 through 4.38.

The first consideration evaluated was the requirement for high and low altitude area coverage according to Task Force requirements [1] within the terminal boundaries. Since this is not a high altitude area coverage study (see Section 4.2), consideration of the high altitude problem was limited to prohibiting removal of any high altitude VORTAC stations. Low altitude area coverage recommended by the Task Force is to support ±4 mile route widths in pre-1977 and 1977, and ±2.5 mile route widths in 1982. In all three cases the service area of VORTAC in terms of its required accuracy [1] and the stated route width exceeds the forty-mile frequency protection limit for low altitude VORTAC stations. Therefore, forty miles was used as the range limit in this analysis. As a matter of fact, the accuracy service area using existing, unimproved VORTAC stations, but with the Task Force specified route widths and accuracies for other system error elements, would be 91.5 nm in 1977 and 60.8 nm in 1982, which are both greater than the forty mile frequency protection limit which in most cases takes precedence. For purposes of this study, the provision of low altitude RNAV coverage was limited to area where VOR route coverage exists in those cases where terrain problems were significant. The only area so affected in the four terminals studied was the mountainous region

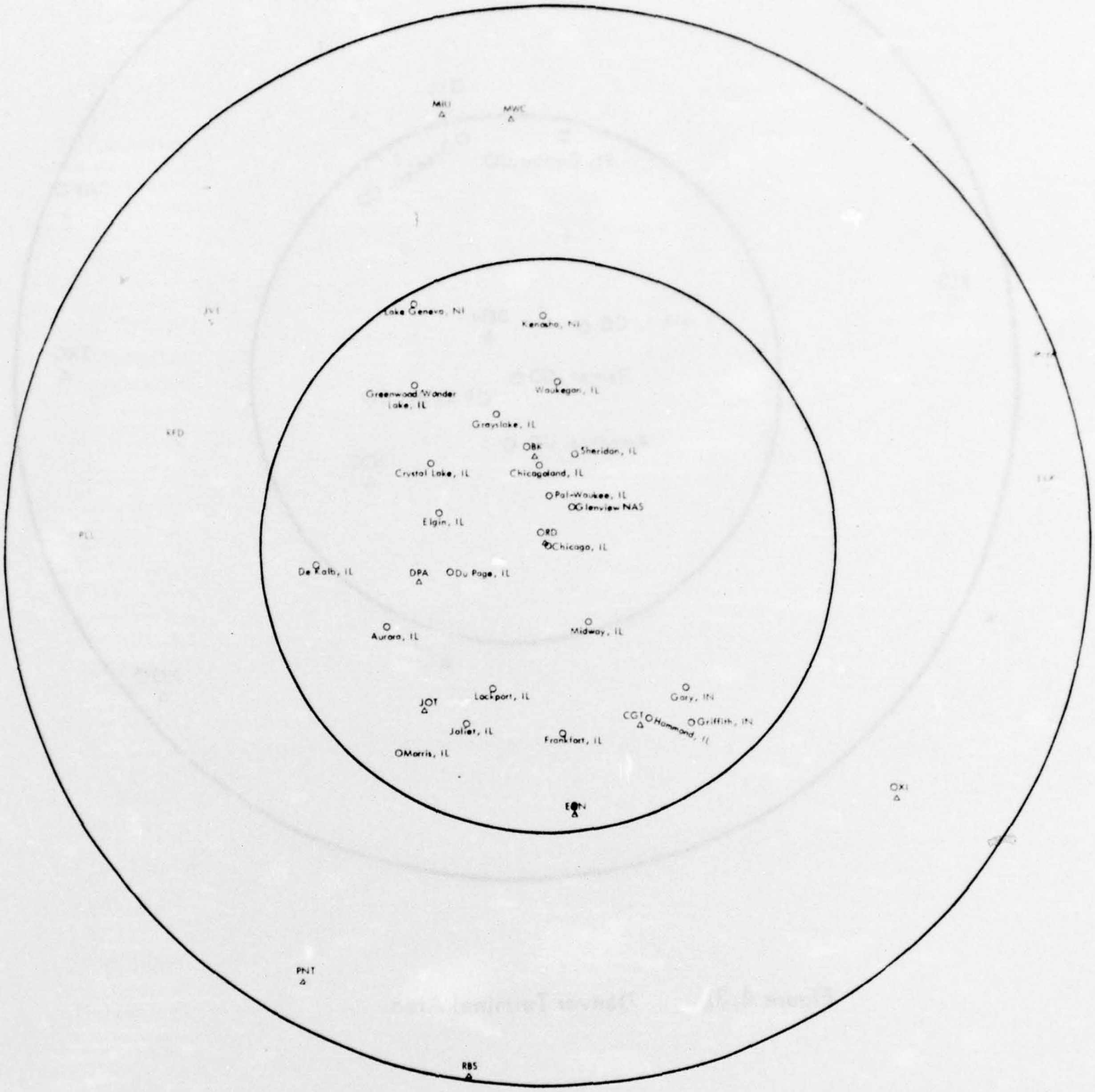


Figure 4.36 Chicago Terminal Area

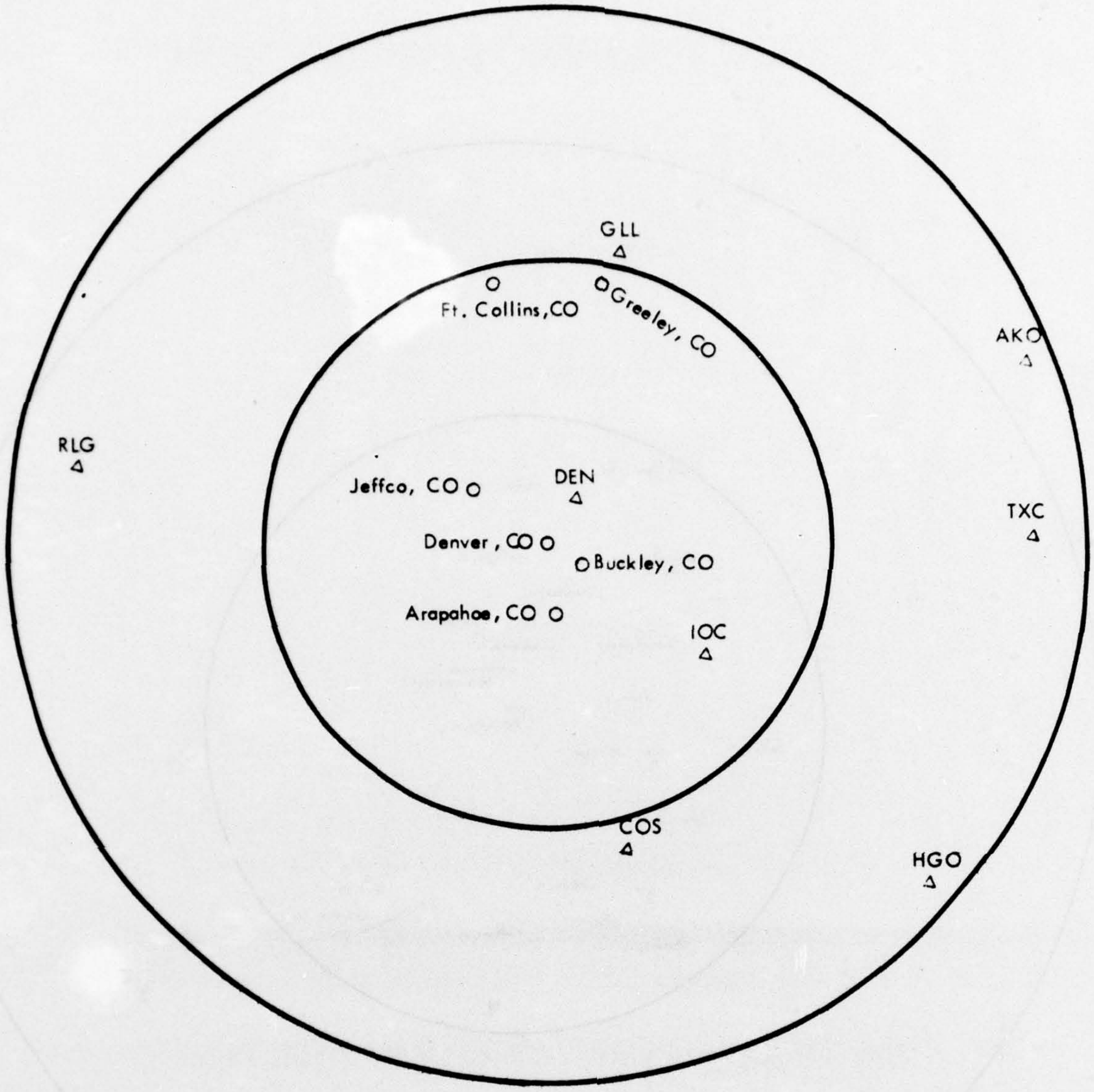


Figure 4.37 Denver Terminal Area

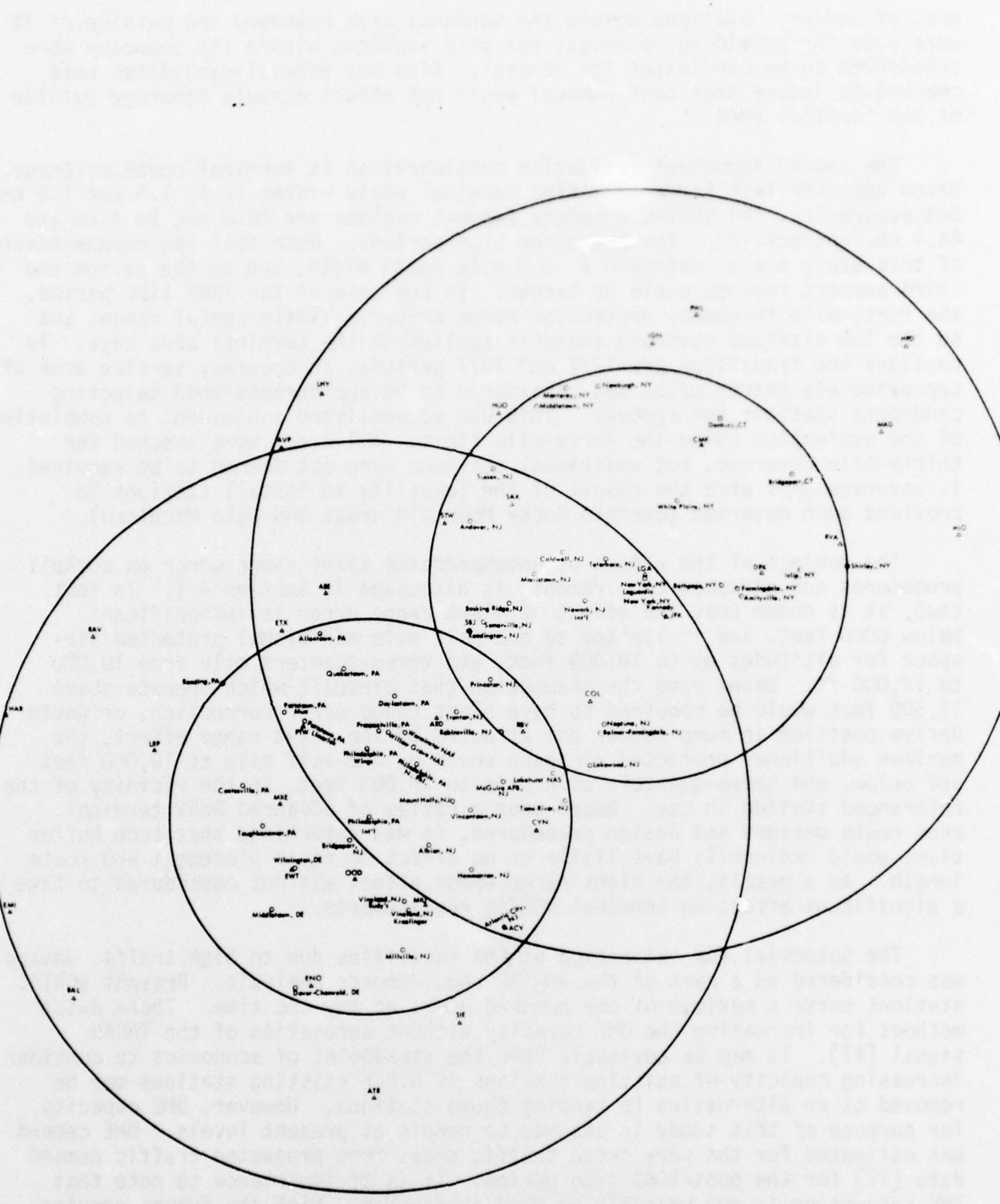


Figure 4.38 Philadelphia and New York Terminal Areas

west of Denver. Stations within the terminal area boundary and outside of it were used for providing coverage, but only stations within the boundary were considered to be candidates for removal. Also any removal candidates were checked to insure that such removal would not affect enroute coverage outside of the terminal area.

The second important evaluation consideration is terminal route coverage. Based upon the Task Force specified terminal route widths (2.0, 1.5 and 1.5 nm) and accuracies, the VORTAC accuracy support regions are 26.8 nm, 29.4 nm and 44.1 nm, respectively, for the three time periods. Note that the recommendations of this study are to maintain a ± 2.0 mile route width, and so the second and third support regions would be larger. In the case of the 1982 time period, the forty mile frequency protection range criteria limits useful range, and so the low altitude coverage analysis applies to the terminal area case. To consider the transition pre-1977 and 1977 periods, an accuracy service area of approximately thirty miles was considered to be appropriate when selecting candidate stations for removal. This was accomplished subsequent to completion of the evaluation using the forty-mile limit. All areas were checked for thirty-mile coverage, but additional stations were not deemed to be required if coverage gaps were the result of the inability to install stations to provided such coverage (certain Rocky Mountain areas and Lake Michigan).

The subject of the effect of uncompensated slant range error on cockpit procedures and airspace requirements is discussed in Section 4.1. In that study it is shown that the effect of slant range error is insignificant below 8000 feet, and is limited to one-half mile additional protected airspace for altitudes up to 10,000 feet, and three-quarters mile from 10,000 to 12,000 ft. Based upon the assumption that aircraft which operate above 12,500 feet would be required to have slant range error correction, or would derive position in some manner not affected by the slant range effect, the maximum additional protected airspace would be one-half mile at 10,000 feet and below, and three-quarters of a mile to 12,000 feet, in the vicinity of the referenced station in use. Based upon a review of advanced RNAV terminal area route designs and design procedures, it was determined that such buffer sizes would ordinarily have little or no effect on route placement and route length. As a result, the slant range error effect was not considered to have a significant effect on terminal VORTAC requirements.

The potential for saturation of DME facilities due to high traffic demand was considered as a part of the VORTAC requirements analysis. Present VORTAC stations serve a maximum of one hundred users at any one time. There exist methods for increasing the DME capacity without derogation of the TACAN signal [47]. It may be advisable from the standpoint of economics to consider increasing capacity of existing stations if other existing stations may be removed as an alternative to keeping those stations. However, DME capacity for purpose of this study is assumed to remain at present levels. DME demand was estimated for the very dense traffic areas from projected traffic demand data [21] for the post-1982 time period. It is of importance to note that DME saturation is not uniquely an RNAV phenomenon. With the future requirement for DME at several terminal areas being highly probable, DME saturation could occur in the near future if DME capacity improvements are not made even without the implementation of RNAV as the primary navigation system.

As a baseline for comparison with VORTAC station requirements given an RNAV-oriented environment, it is desirable to determine the requirement for VORTAC stations for terminal procedures presuming that RNAV would not be implemented. This analysis has been pursued in previous studies [13] and was based upon the presumption that, to a certain extent in busy terminal areas, VORTAC requirements would increase roughly in proportion to IFR traffic demand. This line of reasoning probably overstates the expected growth in VORTAC installations to some extent for two reasons. First, the requirement for DME capability at certain busy terminal areas is under active consideration. This would tend to increase the number of arrival, departure and holding fixes which could be supported by a given station. Of course this still does not provide the flexibility of routings and holding pattern orientations available with RNAV. Secondly, the typical approach taken by terminal control facilities in the face of a shortage of arrival fixes, for example, has been to use VORTAC stations further out from the airport(s). A major problem with this approach has been the lengthening of radar vector routings and an increase in workload on arrival control positions. In light of these factors it was decided that, even though station requirements would grow over the years, the number of new stations required presuming continuation of the VOR-oriented environment into the post-1982 time period probably would not be as great as the number which could be removed, given that RNAV is implemented. While this significantly understates the case for RNAV, the existing VORTAC structure was used for the baseline for present purposes due to the difficulty associated with accurately predicting the growth in VORTAC station requirements presuming continuation of the VOR environment.

In any case where a VORTAC station is being considered as a candidate for removal, the approach procedures which exist at nearby airports which depend upon that station must be taken into consideration. In order to insure that the removal of stations selected during this analysis would not degrade overall service in the terminal area, it was stipulated that all existing VOR and RNAV approach procedures depending on those stations would be replaced by RNAV approach procedures using one of the remaining stations. Also, in cases where an airport is served by only one approach procedure, and it is a VOR procedure dependent upon such a station, it would be replaced with both an RNAV approach and a VOR circling approach using the remaining stations. All such approach procedures were designed in detail in accordance with the procedure design and obstacle clearance requirements in Reference 48. In the case of each RNAV approach, the locations of the Missed Approach Point, Final Approach Fix and Intermediate Approach Fix were determined (lat-lon and rho-theta) for a straight-in RNAV approach. For obstacle clearance purposes, the primary and sencondary obstacle clearance areas were selected for the final approach course and the intermediate approach course (see Figure 4.39 taken from Appendix 2, Reference 49). The obstacle clearance areas required are as follows:

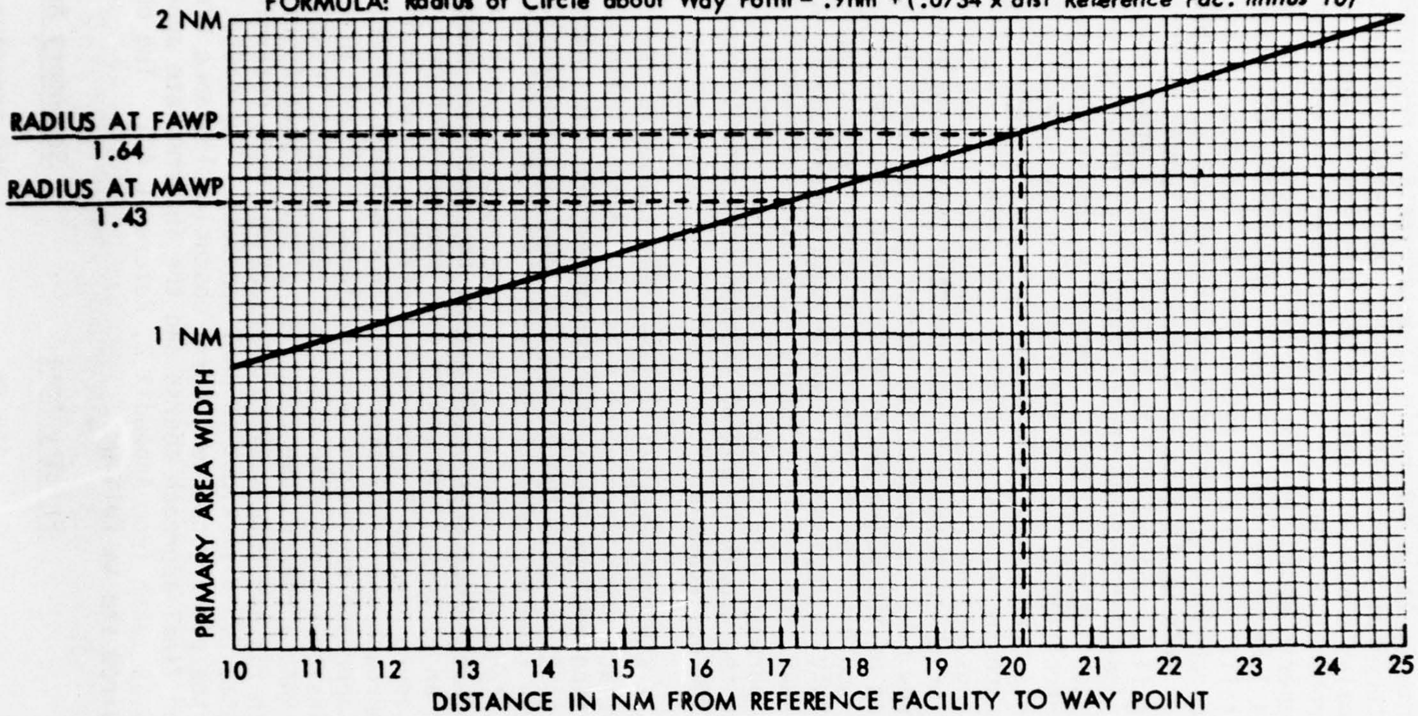
Route Segment	Primary Area	Secondary Area
Final Approach	250 ft	250 tapering to 0 ft
Intermediate Approach	500 ft	500 tapering to 0 ft
Initial Approach	1000 ft	500 tapering to 0 ft

AREA NAVIGATION

FINAL APPROACH COURSE PRIMARY AREA

BEYOND 10 N.M. FROM FACILITY

FORMULA: Radius of Circle about Way Point = .9nm + (.0734 x dist Reference Fac. minus 10)



EXAMPLE: Missed approach Way Point (MAWP)
17.2 NM from Reference Facility
Radius (1/2 Primary area) = 1.43 NM

Final approach Way Point (FAWP)
20.1 NM from Reference Facility
Radius (1/2 Primary area) = 1.64 NM

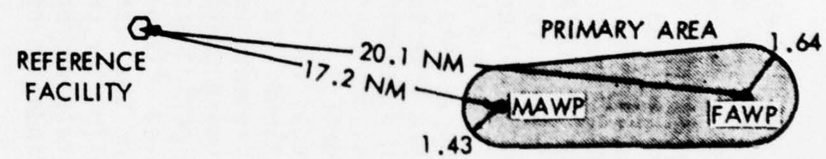


Figure 4.39 RNAV OBSTACLE CLEARANCE AREA DIMENSIONS

Obstacle locations were determined from existing Jeppesen approach plates. Minimum altitudes for each approach segment were determined graphically. Also, recommended descent rate limits and the minimum 40:1 missed approach surface requirements were checked. The mimimums so determined were compared with the existing VOR minimums. In any cases where RNAV minimums were significantly higher than existing VOR minimums, the RNAV approach was discarded, and the VORTAC station which was the candidate for removal was retained. It was necessary to design three such RNAV approach procedures for Chicago, none for Denver, nineteen for Philadelphia and nine for New York. In most cases the resulting RNAV minimums were equivalent to or lower than the VOR minimums (usually when a circling approach was replaced). Note that approaches were designed for all airports affected by the removal of a VORTAC, whether within the terminal area boundary or outside of it.

In those cases where an RNAV approach could be successfully designed, but where the VOR procedure replaced was the only procedure available for that airport, VOR compatibility was maintained by designing a VOR circling approach using the reference facility selected for the RNAV approach for primary guidance. Design of VOR circling approaches is somewhat more involved than is the case for RNAV approaches. Primary and secondary obstacle clearance areas must be allocated as before (but of different dimensions) on the initial, intermediate and final approach courses. In addition, the circling area around the airport must be defined for obstacle clearance purposes, and its dimensions vary with approach category (A,B,C,D,E). Also the lowest standard circling minimums which may be applied are a function of approach category. Furthermore, the Final Approach Fix must be designated using a crossing radial from another VOR (or other radio navigation device). This fix must be provided within certain specified accuracy limits. The missed approach surface also is affected by the accuracy to which the Final Approach Fix is defined. It was necessary to design two such VOR approaches for Chicago, none for Denver, six for Philadelphia and six for New York. In most cases the resulting minimums were equivalent to those of the circling approaches replaced, but were higher than the straight-in approaches replaced.

4.3.2 Results

In Table 4.12 the results of these analyses are presented for each terminal area. In summary, approximately forty percent of all low and high altitude VORTACs within the terminal areas may be removed (only low altitude stations would be removed). Briefly, the results of each analysis are as follows:

CHICAGO (Figure 4.36) - Area and route coverage may be provided in the Chicago area by OBK, ORD, JOT and CGT within the terminal area, and ELX outside of it. The removal of DPA required designation of RNAV approaches at three airports, all of which were suitable replacements for existing VOR approaches. OBK and JOT were retained since they are high altitude facilities, with ORD and CGT filling in needed coverage. Terrain presented no problems and DME saturation would not be a problem with the complement of stations selected. Terminal route coverage (based on 1977 criteria) was provided everywhere except the extreme northeast sector, which is prevented by the existence of Lake Michigan.

DENVER (Figure 4.37) - Area and route coverage may be provided in the Denver area, except in the mountainous region west and northwest of Denver which presently has no low altitude coverage, by DEN (which is a high altitude facility) within the terminal area and TXC, COS and RLG exterior to it. The removal of IOC did not present any problems since it is not used for any instrument approach procedures. DME saturation is not a problem at Denver. Terminal route coverage gaps based on 1977 accuracy criteria (30 mile coverage radius) were not considered to be critical, since the mountainous terrain prevented provision of coverage.

PHILADELPHIA (Figure 4.38) - Complete area and route coverage may be provided at Philadelphia by RBV, CYN (which are high altitude facilities), OOD and PTW, all within the Philadelphia area. ENO was also included since the VOR approach procedure it supports (Dover, Delaware) could not be adequately replaced with an RNAV procedure. ACY was included in order to complete terminal route coverage (1977 criteria) in the southeastern sector. Terrain is not a problem at Philadelphia except that it had to be considered in selecting support reference facilities for certain of the RNAV approach procedures. With this complement of VORTACs, DME saturation is not a problem.

NEW YORK (Figure 4.38) - Complete area and route coverage may be provided at New York by JFK, SAX, RBV (which are high altitude facilities; note that RBV supports Philadelphia also), RVH and SBJ. LGA is also included in order to avoid DME saturation. Terrain is not generally a problem except in the selection of reference facilities for RNAV approach procedures. IGN, which is exterior to the terminal area, was also included in order to provide area and terminal route coverage in the northern part of the terminal area.

Table 4.12 Summary of VORTAC Requirements

Terminal Area	VORTACs Remaining	VORTACs Removable	Per Cent Removable
Chicago	OBK(H), ORD, JOT(H), CGT	DPA, EON	33%
Denver	DEN (H)	IOC	50%
Philadelphia	RBV(H), CYN(H), ACY, OOD, ENO, PTW	ARD, MIV, EWT, MXE	40%
New York	RVH, LGA, JFK(H), RBV(H), SBJ, SAX(H)	CMK, DPK, COL, STW	40%

/Note/ The parenthetical "H" means the station is a high altitude VORTAC

In order to demonstrate the advantages in terms of improved landing minimums which can often be gained from their use, the results of the RNAV approach procedure design efforts are presented in Table 4.13. It is evident from these results that there may be much to be gained from the establishment of RNAV procedures at other airports as well. Also, in order to document the results of the VOR circling approach procedure design effort, the landing minimums which resulted are presented in Table 4.14. Both the straight-in and circling minimums of the procedure replaced are listed. Note that the new circling minimums are on a par with, but usually slightly better than, the old circling minimums. While the specifications and requirements in [48] were strictly adhered to in the design process, it is possible that more conservative standards were applied in designing the published procedures, or that flight checking resulted in recommendations for slightly higher minimums. It should also be noted that, while the landing minimums are on a par with the existing approaches, the procedures themselves are less advantageous since they often require more severe maneuvers to align with the runway, and since they involve higher workload due to the necessity for a cross-radial used as the Final Approach Fix. Note that this is in contrast to the case of the RNAV procedures, which were for the most part more advantageous than the VOR procedures they replaced.

In order to reflect the economic impact of the savings which may be gained by removing (or relocating) the stations which are candidates for removal, it is necessary to first identify the types of savings which may be realized. The direct savings (those directly related to the removal of a station) include elimination of maintenance expense, prevention of routine equipment replacement or upgrading, prevention of need for eventual upgrading to DVOR status and release of real estate for other use. Routine maintenance and operating costs may be presumed to be 8% of new equipment installation cost [50], or $48,500 annually for a dual VORTAC installation. The modernization of stations (conversion to solid state equipment, etc.) is not easily quantified in terms of cost, since data describing which stations require modernization is not available; however, older equipment in remaining stations could be replaced by removed new equipment, where available. The upgrading of status of stations to DVOR would, of course, not be necessary for those removed. This is an important consideration since many stations would require upgrading even if RNAV were to not be implemented. Conversion to doppler VOR costs $160,500 for a dual station[44]. The potential value of real estate which could be disposed of is not estimated here, although it could be a significant factor since many of these sites are within or near metropolitan areas.

Upon review of the VORTAC requirements results determined above, which showed a range of savings from 33% to 50% at the four terminal areas studied, it is apparent that stations may be removed on a consistent basis. Review of the Denver case, however, reveals that it is a special case, since it would not be ordinarily expected that an entire terminal area could be supported with a single station (plus support from surrounding stations) which was the case in Denver due to the prohibitively high terrain to the west. Therefore, for purpose of extrapolating these results to terminal areas in general, the figure of 40% savings be used, but that it only be applied to terminal areas where at least four VORTAC stations already exist.

Table 4.13 RNAV Approach Procedure Design Results

Terminal Area	Airport	Procedure	Minimums	Procedure Replaced	Minimums Replaced
Philadelphia	Trenton, NJ(Mercer)	RNAV-6(RBV)	700(487)	VOR-A(ARD)	700(487)
	Trenton, NJ(Mercer	RNAV-24(RBV)	620(407)	VOR-24(ARD)	740(527)
	Trenton, NJ(Mercer)	RNAV-34(RBV)	620(420)	RNAV-24(ARD)	620(420)
	Trenton, NJ(Mercer)	RNAV-16(RBV)	620(407)	RNAV-16(ARD)	740(527)
	North Philadelphia	RNAV-33(RBV)	540(432)	RNAV-33(ARD)	460(352)
	North Philadelphia	RNAV-15(PTW)	700(580)	RNAV-15(PTW)	700(580)
	Coatesville, PA(Chester)	RNAV-29(PTW)	980(318)	VOR-29(MXE)	1060(398)
	Vineland, NJ(Rudy's)	RNAV-26(ACY)	460(380)	VOR-A(MIV)	580(500)
	Vineland, NJ(Kroelinger)	RNAV-28(ACY)	540(453)	VOR-28(MIV)	520(433)
	Hammonton, NJ	RNAV-3(ACY)	320(251)	VOR-A(MIV)	600(531)
	Albion, NJ	RNAV-4(OOD)	480(330)	VOR-4(MIV)	740(590)
	Millville, NJ	RNAV-23(OOD)	420(333)	VOR-23(MIV)	540(453)
	Toughkenamon, PA	RNAV-24(OOD)	840(404)	VOR-24(MXE)	900(464)
	Philadelphia International	RNAV-9R(OOD)	520(497)	VOR-9R(EWT)	680(657)
	Philadelphia International	RNAV-27R(OOD)	540(529)	VOR/DME-27R(MXE)	540(529)
	Middletown, DE(Summit)	RNAV-17(OOD)	520(449)	VOR-A(EWT)	600(529)
	Wilmington, DE	RNAV-9(OOD)	480(401)	VOR-9(EWT)	420(341)
	Wilmington, DE	RNAV-32(OOD)	480(405)	VOR-32(EWT)	540(465)
	Dover, DE(Cheswold)	RNAV-27(OOD)	700(645)	VOR-27(ENO)	400(345)
Chicago	Aurora, IL	RNAV-27(JOT)	1140(434)	VOR-A(DPA)	1220(514)
	Chicago, IL(DuPage)	RNAV-10(ORD)	1180(424)	VOR-10(DPA)	1180(424)
	Elgin, IL	RNAV-36(ORD)	1300(510)	VOR-A(DPA)	1380(590)
New York	East Stroudsburg, PA	RNAV-26(SAX)	1320(840)	VOR/DME-A(STW)	1480(1000)
	Andover, NJ	RNAV-3(SAX)	1240(657)	VOR-A(STW)	1480(897)
	Belmar-Farmingdale, NJ	RNAV-14(RBV)	500(343)	VOR-A(COL)	600(443)
	Neptune, NJ	RNAV-9(RBV)	640(540)	VOR-A(COL)	660(560)
	Danbury, CN	RNAV-8(PWL)	1340(883)	VOR-A(CMK)	1400(943)
	Newark, NJ	RNAV-11(JFK)	700(682)	RNAV-11 (COL)	860(842)
	Amityville, NY(Zahn's)	RNAV-28(JFK)	420(366)	VOR-1(DPK)	600(546)
	Farmingdale, NY	RNAV-19(JFK)	560(478)	VOR-A(DPK)	560(478)
	Bethpage, NY	RNAV-33(JFK)	500(368)	VOR-A(DPK)	540(408)

Table 4.14 VOR Circling Approach Minimums

Terminal Area	Airport	Approach Category	New Procedure Circling Minimums	Procedure Replaced	Straight-in Minimums	Circling Minimums
Philadelphia	Coatesville, PA (Chester)	A	1020 (358)	VOR-29 (MXE)	1060 (398)	1140 (478)
		B	1120 (458)		1060 (398)	1140 (478)
		C	1120 (458)		1060 (398)	1200 (538)
		D	1220 (558)		1060 (398)	1280 (618)
	Vineland NJ (Rudy's)	A	560 (480)	VOR-A (MIV)	--	580 (500)
	Vineland NJ (Kroelinger)	A	540 (447)	VOR-28 (MIV)	520 (433)	580 (487)
	Hammonton, NJ	A	560 (491)	VOR-A (MIV)	--	600 (531)
		B	560 (491)			600 (531)
		C	560 (491)			600 (531)
		D	620 (551)			620 (551)
	Albion, NJ	A	680 (530)	VOR-4 (MIV)	--	740 (590)
	Toughkenamon, PA	A	880 (444)	VOR-24 (MXE)	900 (464)	900 (464)
Chicago	Aurora, IL	A	1180 (474)	VOR-A (DPA)	--	1180 (474)
		B	1180 (474)			1180 (474)
		C	1180 (474)			1180 (474)
		D	1260 (554)			1260 (554)
	Elgin, IL	A	1360 (570)	VOR-36 (DPA)	1320 (530)	1420 (630)
		B	1360 (570)		1320 (530)	1420 (630)
		C	1360 (570)		1320 (530)	1420 (630)
		D	1360 (570)		1320 (530)	1420 (630)
New York	East Stroudsburg, PA	A	1260 (780)	VOR DME- (STW)	--	1480 (1000)
	Andover, NJ	A	1340 (757)	VOR-A (STW)	--	1480 (897)
	Belmar-Farmingdale, NJ	A	540 (383)	VOR-A (COL)	--	600 (443)
		B	620 (463)			620 (463)
		C	620 (463)			620 (463)
		D	720 (563)			720 (563)
	Neptune, NJ	A	640 (540)	VOR-A (COL)	--	660 (560)
		B	700 (600)			660 (560)
		C	700 (600)			660 (560)
		D	840 (740)			660 (560)
	Danbury, CN	A	1380 (923)	VOR-A (CMK)	--	1400 (943)
		B	1380 (923)			1400 (943)
		C	1380 (923)			1400 (943)
		D	1380 (923)			1400 (943)
	Bethpage, NY	A	540 (408)	VOR-A (DPK)	--	540 (408)
		B	600 (468)			600 (468)
		C	600 (468)			640 (508)
		D	700 (568)			700 (568)

A survey of the high and medium density terminal areas has been performed in order to determine the number of low and high altitude VORTAC stations resident in each area (within 45 miles). The results are presented in Tables 4.15(high density) and 4.16 (medium density). Note that the totals of those terminals with four or more stations are presented separately, and totals 120 stations all together. Forty percent of these, 48 stations, could therefore be removed while maintaining full services and coverage. Note that this does not include the many low density terminal areas to which these criteria could also apply.

In summary, the annual maintenance savings which would accrue due to the removal of forty-eight stations would be $2.33 million. This amount, of course, is exclusive of any ordinary modernization costs, such as would be required for conversion to solid state equipment, etc. The one-time cost savings which could be realized by not requiring the conversion to doppler VOR for the removed stations would be $4.84 million.

The results presented here are quite conservative since the baseline used for comparison was the assumption that no additional VORTAC installations would be required for terminal area purposes if RNAV were not implemented. This would clearly not be the case. The NAS Plan [51] states that five new stations will be installed per year, although it does not present a

Table 4.15 Terminal VORTAC Stations - High Density Terminals

Terminal	Low	High	Total	≥4
Atlanta	2	1	3	
Boston	2	3	5	5
Chicago	3	2	5	5
Cleveland	4	2	6	6
Dallas	4	1	5	5
Denver	1	1	2	
Detroit	2	1	3	
Houston	2	2	4	4
Los Angeles	4	3	7	7
Memphis	1	1	2	
Miami	0	2	2	
New York	7	3	10	10
Phoenix	2	3	5	5
Philadelphia	8	1	9	9
Pittsburg	4	1	5	5
San Antonio	0	1	1	
San Diego	2	2	4	4
San Francisco	6	1	7	7
St. Louis	2	1	3	
Washington	7	2	9	9
TOTAL	63	34	97	81

Table 4.16 Terminal VORTAC Stations - Medium Density Terminals

Terminal	Low	High	Total	≥4
Albany	3	1	4	4
Albuquerque	1	2	3	
Birmingham	4	1	5	5
Bradley	7	1	8	8
Buffalo	1	2	3	
Charlotte	2	0	2	
Cincinnati	2	0	2	
Columbus	1	1	2	
Dayton	2	1	3	
Des Moines	1	1	2	
El Paso	1	1	2	
Indianapolis	3	1	4	4
Jacksonville	0	2	2	
Kansas City	3	1	4	4
Knoxville	1	1	2	
Las Vegas	0	2	2	
Louisville	2	1	3	
Minneapolis	1	1	2	
Milwaukee	0	2	2	
Nashville	1	1	2	
New Orleans	3	1	4	4
Norfolk	4	1	5	5
Oklahoma City	0	2	2	
Omaha	1	2	3	
Orlando	0	2	2	
Portland	0	2	2	
Providence	2	3	5	5
Raleigh-Durham	1	1	2	
Rochester	2	1	3	
Sacramento	1	2	3	
Salt Lake City	1	2	3	
Syracuse	2	1	3	
Tampa	0	3	3	
Tulsa	1	1	2	
TOTAL	54	47	101	39

breakdown as to purpose (terminal or enroute). The added stations are quite costly on an annual basis in comparison with the savings associated with the removal of stations, since the acquisition cost must be amortized over the useful life of the station. The total annual cost (maintenance plus amortization costs) per station [13] would be $103,000 for a single transmitter station and $128,000 for a dual installation. If RNAV could alleviate the requirement for some of these stations, equivalent savings would result.

4.4 PRELIMINARY ANALYSIS OF THE RNAV IMPACT ON ATC AUTOMATION

This section discusses the various ways in which the phased implementation of RNAV can affect plans for the continued development and implementation of Third Generation and Upgraded Third Generation ATC Automation. In those areas where a potential effect on terminal or enroute automated ATC capabilities is expected, further efforts have been made to quantify those effects on cost-sensitive factors.

4.4.1 Areas of Potential Impact

A total of six areas in ATC automation were determined to exhibit potential for impact in one or more of the three RNAV implementation phases. These phases have been considered both in the manner described by the Task Force [1] and as modified during this study, with emphasis on the latter. The terminal area ATC facets impacted include the definition and charting format of RNAV routes, the conflict prediction problem, and arrival aircraft metering and spacing (M&S). While the enroute areas with potential for impact also include the definition of RNAV routes and the conflict prediction problem, enroute flow control could also be affected. The types of ATC automation impacts considered include core storage requirements, software development, computer time usage, and other hardware requirements. It should be recognized that, while variations in three of these factors can directly impact cost, computer time utilization does not necessarily directly affect costs. Instead, the overall processing capacity of a given ATC facility installation is limited by the computing speed available and tasks required to be performed. When a new task or combination of tasks exceeds this capacity, a major upgrade in equipment may be required which could be very costly. However, where sufficient capacity is available, new tasks have no significant effect on costs.

The following section quantifies, where appropriate, the specific impact of RNAV in these six areas. For the most part the impacts were found to be minimal or even favorable. However, should preplanned direct operations be implemented extensively, a significant impact on computer time utilization could result which could have a cost impact at those ARTC Centers which are at or near the existing computer time capacity.

4.4.2 Quantification of Impact

4.4.2.1 RNAV Route Definition Impact

The introduction of RNAV routes or preplanned direct operations has an impact, particularly enroute, on ATC system computer resources. The ATC equipment so impacted are primarily the computer core storage requirements and and computer time utilization. Any needed software development would occur during the routine software modification process. Other ATC automation facilities would not be affected. The major effect of introducing an expanded RNAV route structure is to increase the number of routes in any given ARTCC and so to increase the number of routes which must be adapted to the center coordinates. As the total number of routes increases (particularly over the short term), core requirements will likewise increase. Computer time utilization is unaffected in this case. When preplanned direct route flight plans

become common, however, computer time utilization will be affected. The NAS Stage A computer software is presently capable of processing direct routes, and so additional software development is not required. Computer time utilization is affected by each pre-planned direct route filed since each center computer system affected must adapt the individual route to center coordinates. Core storage is not affected since the route description tables so created are identical to those created for conventional flight plans. The introduction of RNAV routes is not expected to significantly impact terminal ARTS system requirements, primarily since the ARTS system is not route-oriented.

A method has been developed [52] for determining the impact of implementing RNAV structures on ARTCC computer core requirements. Estimates were also made in that report of the effects of preplanned direct routes on computer time utilization. Since computer time utilization is not necessarily a direct system cost factor, it is not considered further here. Instead, the incremental core requirements due to the introduction of the RNAV route structure have been estimated. In all of these analyses, the results presented in Reference 52 have been reorganized in order to conform to the revised RNAV implementation plan presented in this report. The pertinent features of that plan as applied to this analysis are summarized below:

Phase I: High Altitude - VOR and RNAV structures as they presently exist. Very limited preplanned direct.
Low Altitude - Present VOR structure plus limited RNAV structure. Very limited preplanned direct.

Phase II: High Altitude - Extended RNAV structure and no VOR routes. Limited preplanned direct.
Low Altitude - Extended RNAV structure and realigned, reduced VOR structure complexity. Very limited preplanned direct.

Phase III: High Altitude - Same RNAV structure plus extensive preplanned direct.
Low Altitude - Same structures plus limited preplanned direct.

The Phase 1 analysis presumes that the high altitude RNAV structure will be of the same complexity as the present RNAV structure. Furthermore, a low altitude RNAV structure will be implemented. The extent of the low altitude RNAV structure in each ARTC center is assumed to be proportional to the number of high altitude RNAV routes. The proportionality factor in each case is taken to be 50% (to reflect limited implementation in Phase I) of the ratio of existing low altitude to high altiude VOR routes.

The Phase II analysis presumes an RNAV structure which is at least as complex (in each ARTC center) as the more complex of the existing VOR or RNAV structures. In addition, the complexity has been inflated 25% to account for limited parallel routes and additional city-pair coverage. That is to say, the high altitude RNAV structure is presumed to be 25% more complex than the existing RNAV or VOR structure whichever is more complex than the present existing VOR/RNAV combination. The Phase II low altitude RNAV structure is

Table 4.17 Additional RNAV Route Core Storage Required by Center, Phase I

Center	Existing High Altitude RNAV Routes	Existing High Altitude VOR Routes	Existing Low Altitude VOR Routes	Present Route Core Storage Usage(K-Words)	Estimated Low Altitude RNAV Routes	Additional Core Storage Required (K-Words)
NYC	25	31	70	24.5	28	4.8
LAX	30	30	39	18.9	20	3.4
ATL	31	23	69	23.7	47	8.0
IND	22	22	81	24.3	41	7.0
CHI	44	29	76	28.5	58	9.9
BOS	9	37	47	18.3	6	1.0
CLE	23	33	83	27.1	29	4.9
MKC	23	26	63	21.7	28	4.8
HOU	20	22	45	16.8	20	3.4
DCA	20	25	54	19.2	22	3.7
FTW	23	28	64	22.3	26	4.4
OAK	22	13	38	13.9	32	5.4
DEN	26	30	45	19.4	19	3.2
MIA	10	14	28	10.1	10	1.7
MEM	16	22	52	17.5	19	3.2
MSP	23	34	75	25.7	25	4.3
SEA	14	22	38	14.4	12	2.0
JAX	20	20	31	13.6	16	2.7
ABQ	20	32	53	20.4	17	2.9
SLC	19	25	61	20.4	23	3.9
AVERAGE	23	26	56	20.0	25	4.3

Table 4.18 Additional RNAV Route Core Storage Required by Center, Phase II

Center	Estimated Low Altitude RNAV Routes	Deleted Low Altitude VOR Routes	Estimated High Altitude RNAV Routes	Existing High Altitude RNAV Routes	Deleted High Altitude VOR Routes	Net Increases In RNAV Routes	Net Decrease In VOR Routes	Additional Core Storage Required (K-Words)
NYC	70	46	39	25	31	84	77	-4.5
LAX	39	25	38	30	30	47	55	-4.9
ATL	93	45	39	31	23	101	68	-0.5
IND	81	53	28	22	22	87	75	-3.7
CHI	115	49	55	44	29	126	78	0.8
BOS	47	31	46	9	37	84	68	-2.7
CLE	83	54	41	23	33	101	77	-2.3
MKC	63	41	33	23	26	73	67	-3.9
HOU	45	29	28	20	22	53	51	-3.3
DCA	54	35	31	20	25	65	60	-3.6
FTW	64	42	35	23	28	76	70	-4.1
OAK	64	25	28	22	13	70	38	1.5
DEN	45	29	38	26	30	57	59	-4.4
MIA	28	18	18	10	14	36	32	-1.7
MEM	52	34	28	16	22	64	56	-2.9
MSP	75	49	43	23	34	95	83	-4.2
SEA	38	25	28	14	22	52	47	-2.6
JAX	31	20	25	20	20	36	40	-3.3
ABQ	53	34	40	20	32	73	66	-3.7
SLC	61	40	31	19	25	73	65	-3.5
AVERAGE	60	36	35	23	26	73	62	-2.9

presumed to be fully implemented (i.e., the proportionality factor is taken to be 100% of the ratio of existing low altitude to high altitude VOR routes). Also, the VOR structure complexity is assumed to be reduced to 35% of its present state, reflecting the deletion of unnecessary routes and realignment of others. It has been further presumed that twenty percent of all flights (low and high, but mostly high) are, at least in part, preplanned direct (an average of 50% of each such flight plan being direct routings was selected).

The Phase III analysis presumes that route structures of the same complexity exist as in Phase II. However, the role of preplanned direct routings is expected to expand in both the low and high altiude environment.

Data concerning the present number of VOR and RNAV routes within each of the 20 ARTC centers within CONUS are taken from Reference 52. That reference also presents detailed estimates for the amount of computer core storage required (average) for the storage of VOR routes, RNAV routes (Phase I), and RNAV routes (Phases II and III). That reference presumed that the number of fixes required to define RNAV routes to the center computer would be reduced from the present level of twelve per route per center to eight as the Phase II and III periods are reached. This probably results since the VOR structure will have been removed, and so route segment interactions will be reduced. The per route core requirements are as follows:

Environment	Words/Route
VOR	200
RNAV Phase I	170
RNAV Phases II and III	130

Table 4.17 presents the existing high and low altitude route data for each center, and, in addition, the projected Phase I low altitude route structure complexity derived as explained earlier. That table presents both the present core storage usage plus the increment required by the interim low altitude RNAV route structure. On the average the core increase is 4.3 K-words (22%), while the largest increase would occur at the Chicago Center, 9.19 K-words (35%). To put these numbers in perspective, the standard NAS computer core provision is 655.36 K-words.

Table 4.18 presents the results of the Phase II core requirements analysis in which expanded high and low altitude RNAV route structures are projected, and where the high altitude VOR structure is eliminated and the low altitude structure is reduced to 35% of its present complexity. Note that the net core requirement impact is affected both by the changes in numbers of routes of each type and the number of words per route required as described in the preceding table. Table 4.18 indicates that the reorganization of route structures will actually diminish core requirements on average of 2.9 K-words (15%) compared to present usage. Since the only change from Phase II to Phase III is an increase in Preplanned direct filings, this table also applies to the Phase III situation. Additional computer time utilization, required for converting the preplanned direct route data to center coordinates, will increase as the number of preplanned direct flight plans increases as discussed in Reference 51.

4.4.2.2 Impact on Conflict Prediction Requirements

In the enroute environment, a reliable form of conflict prediction based on tracking data and flight plan prediction is a prerequisite to the unconstrained implementation of preplanned direct RNAV operations. Also, of course, some form of general area flight checking for navigation signal coverage will also be required. Plans for development of such a conflict prediction system include basic programs presently under development [52] plus eventual development of advanced programs, even to the point of automated conflict resolution message generation and delivery. Such advanced systems will make use of available tracking information and flight route data for purposes of projecting impending conflict situations. While the implementation of preplanned direct will mean more such routes at any given time, this should not affect the core requirements or even the computer time utilization of the enroute conflict prediction algorithm since the route data will already have been converted to center coordinates (when the flight plan was activated) and since the number of aircraft under examination will not be affected. When automated conflict resolution decision capabilities are implemented, they will be slightly more complex due to inclusion of RNAV conflict resolution techniques along with conventional techniques. However, this effect should be very minor.

Preplanned direct flight plans can be implemented to a certain extent prior to the advent of full scale operational conflict prediction techniques. However, such flight plans will be limited to areas where radar coverage exists. Therefore, where operational advantages exist, the use of preplanned direct flight plans where permissible should receive encouragement. While full scale enroute conflict prediction capability is a requirement for unconstrained preplanned direct, direct routings do not necessarily affect the complexity of the conflict prediction system.

In the terminal environment, the introduction of RNAV aircraft should have no direct effect on conflict detection algorithms (except where automated resolution decision capability is employed, as before). This is due to the probable use of tracking data only, not route data, in the conflict prediction process. Should route data be used, RNAV should improve the situation since the intended routes are well defined in advance, as opposed to radar vector routings.

4.4.2.3 Impact on Enroute Flow Control Program

The enroute flow control program is presently in a developmental stage. Its major purposes include the scheduling and rerouting of aircraft to balance capacity and demand in order to avoid serious delays and diversions. Capacity imbalances can occur due to shifts in demand, or to weather induced problems, or to control or navigation facility outages. The entire system is to consist of a central flow control facility and local flow control data collection and management facilities at each ARTC center. The only area of flow control activity which should be affected by RNAV operations is in the

rerouting function to be used to alleviate severe weather and facility outage effects. In performing this function, the central facility will be afforded more flexibility with the RNAV capabilities, particularly in being able to use the direct or random routing capability and parallel offset capability inherent with RNAV. However, the system will have to be able to deal with more data in order to be able to utilize this increased flexibility. This should not affect individual centers to a significant extent. The degree of effect upon the central facility is difficult to assess until the planned capabilities and functions of the system are more firmly established. However, the inclusion of RNAV should not cause a large perturbation in system complexity.

4.4.2.4 Impact on Terminal Metering and Spacing

The impact of RNAV operations on the core requirements and computer time utilization requirements of arrival metering and spacing concepts currently under consideration has been investigated in Reference 52. In that study the additional program code required for performing M & S with a mixed (RNAV and conventional) environment over that required presuming a conventional environment has been determined to require 0.45 K-words of additional core storage at each ARTS installation. This number is not considered to be very consequential since the projected core requirement for the entire M & S function is 16 K-words. It is particularly inconsequential in view of the benefits which can be made available through the use of 4D RNAV capabilities, as discussed in Section 3.4. In Reference 52 it has also been determined that the effect of RNAV operations on computer time utilization would be of no significance.

4.4.3 Economic Implications of RNAV Automation Impact

The primary RNAV impact determined above concerned computer system core requirements. The problem of determining the cost impact of increased core requirements is not necessarily straightforward. While cost per K-word data is available, determination of true cost is complicated by the fact that in some cases additional core memory may not be added at will, but may be limited by other hardware and program structure considerations. This is particularly true in the enroute environment where all NAS computers (9020A and 9020D models) are currently configured with the maximum planned active core complement (655,360 words). It is physically possible to add more core storage; however, existing software programs would have to be reconfigured in order to accommodate the modified core addressing scheme. Two methods for relaxing the enroute core constraint are presently under investigation: the modification of existing memory units to increase capacity (affecting 9020A sites only); and other hardware and software improvements which include provision of improved flight data displays which have integral data storage capability.

In view of all of the above factors, core storage availability is actually much more valuable than the basic equipment costs involved. When storage resources are in use at or near their limits, and additional capabilities such as RNAV are being evaluated, these planned capabilities must complete with each other for this available space, and so some form of cost figure should be attached to available storage space. The basic equipment costs are as follows:

Environment	System	Core Unit and Cost	Cost/K-Word
Enroute:	9020A	65 K-words, $125,000	$1900
	9020D	132 K-words, $475,000	$3600
Terminal:	ARTS III	16 K-words, $40,000	$2500

It should be noted that additional core storage capability is still available on both the present ARTS systems and the planned enhanced ARTS multi processor systems, and so the stated ARTS core cost is fairly realistic, while the NAS enroute costs should be considered as being extremely conservative. In particular, while the 9020D sytem has the highest per unit cost, there are presently no expansion plans for it, and so therefore its figure is the most conservative of all.

The enroute core requirement due to the implementation of RNAV is fortunately quite small through all three implementation phases. The mean Phase I impact of 4.3 K-words per center could be evaluated at a cost of $12,900 per center, presuming a mean value for core storage of $3000/K-word. In Phase II and likewise Phase III, the impact is a savings of $8700 per site over present VOR structure requirements. Therefore, the cost of the core utilized would be $21,600 less in Phase II than in Phase 1, and this capability could be used to accommodate other system growth requirements. As preplanned direct routes are implemented extensively in Phase III, this level of direct routings may not be feasible at some centers due to the increased computer time required for route adaptation. In contrast, the RNAV increment per ARTS III site due to inclusion of RNAV in the metering and spacing system is an inconsequential $1100. This is particularly small in view of the benefits which RNAV, and 4D RNAV in particular, can provide to the M and S function.

4.5 IMPACT OF VNAV ON AIRSPACE CAPACITY

The RNAV operational concept described in Section 5 of this report includes the assignment of fixed altitudes and/or altitude restrictions as an integral part of the design of terminal area SIDs and STARs. It is possible to designate altitudes, or altitude restrictions, at a horizontal position, either by the explicit assignment of altitude at that point or implicitly by specifying a fixed gradient 3D route whose centerline passes through the geographical point of interest at the desired altitude. Fixed gradient 3D routes could be specified in either of two ways: (1) specified gradient or (2) specified altitudes. In the first case, the vertical profile of the 3D route is described by a 3 dimensional point in space from which a specified vertical gradient route emanates. In the second case, the gradient of the route is determined by drawing a straight line between two geographical points each of which has a specified altitude or altitude limit. The Task Force considered that 3D routes offered a potential for increasing airspace capacity.

This section presents an analysis of the potential of fixed gradient 3D routes as a design tool for the airspace planner to increase airspace capacity. 2D versus 3D vertical separation requirements are examined for crossing routes, and a comparison is made of the airspace required and the number of waypoints or altitude restriction points required for 2D and fixed gradient 3D routes. Finally, an analysis is presented of additional airspace requirements and operational constraints associated with climbing and descending parallel offset routes. They are examined for both fixed gradient 3D routes and procedural altitude control on 2D routes, and include the separation and operational problems associated with parent route or offset turnpoints in the vicinity of a crossing or intersecting route.

The results of this analysis support the conclusion that the use of fixed gradient 3D routes for procedural separation and/or the requiring of 3D capability for entry into certain airspace does not appear to offer sufficient payoff in either airspace capacity or operational utility to warrant consideration. A corollary of this conclusion is that the terminal area design approach recommended in Section 5 of this report need not be constrained by a requirement for fixed gradient 3D routes. Therefore, optimum arrival and departure routes may be designed on the basis of providing the shortest path length and most efficient altitude profiles for 3D equipped aircraft, and 2D equipped aircraft can also utilize these profiles. Additional economic benefits are available to 3D equipped aircraft through pilot selection of 3D gradients, as discussed in Section 3.1.

4.5.1 Separation Requirements

Vertical and horizontal separation have always been provided independently-i.e., the joint probability distribution is not considered in assigning separation, and both the horizontal and vertical separation requirements are met in assigning altitude restrictions. The technique selected for VNAV

separation [2] is the time-proven separation concept of utilizing 2 σ errors in the horizontal plane and 3 σ errors in the vertical plane. The along track error, reflected into the vertical plane, is not directly additive, but is considered a part of an error budget whose elements are combined in an RSS manner.

When the along track error is considered in this way, crossing routes may be described as "tubes" with rectangular cross sections whose dimensions describe the 2 σ horizontal, and 3 σ vertical, total system errors and the required vertical separation between the center lines of these routes may be derived geometrically by placing the routes such that edges of the "boxes" just touch. This technique was applied in the derivation of vertical separation requirements in Reference 2.

The consideration of along track error as a part of the vertical error budget is certainly an acceptable expedient. It does not, however, provide for a convenient method of computing the horizontal location of positions at which altitude restrictions may be applied to insure vertical separation of crossing RNAV (2D) routes, or for the crossing of a 2D route by a 3D route where an altitude restriction is necessary on the 2D route.

4.5.2 RNAV Separation (2D/2D)

Consider the crossing route situation depicted in Figure 4.40. The route widths L_1 and L_2 represent the total 2 σ cross track error of each route. The routes are both descending, as indicated by the arrows on the route centerline, and it is assumed that route #1 will cross over route #2. It is desired to establish two altitude restriction points to provide for procedural separation.

In determining the point along route #1 at which to place the restriction, the effective width of route #2 must be considered. It consists of two elements: 1) the width of route #2 at the crossing angle θ: $\left|\frac{L_2}{\sin\theta}\right|$, and 2) the additional width of route #2 due to the width of route #1: $\left|\frac{L_1}{\tan\theta}\right|$

The longitudinal uncertainty of position on route #1 must also be taken into account. (This is the error which was accommodated in the VNAV case by making it a part of the vertical error budget). This along track error on route #1 may be considered as an additional element in the effective route width of route #2, but it should not be combined RSS, as it was in the VNAV case. In the VNAV case, the along track error on route #1 is but one element of the VNAV error on route #1. In this case (RNAV), it is the total error, along one coordinate of the horizontal plane for route #1, and is being combined with the other elements of the effective width of route #2 only for geometric convenience. The RTCA committee on Area Navigation, SC-116E, recommended the inclusion of along track error, reflected into the vertical, as part of the VNAV error budget [17] and it is included in this comparison of 2D and 3D operation to maintain consistency. The selection of an along

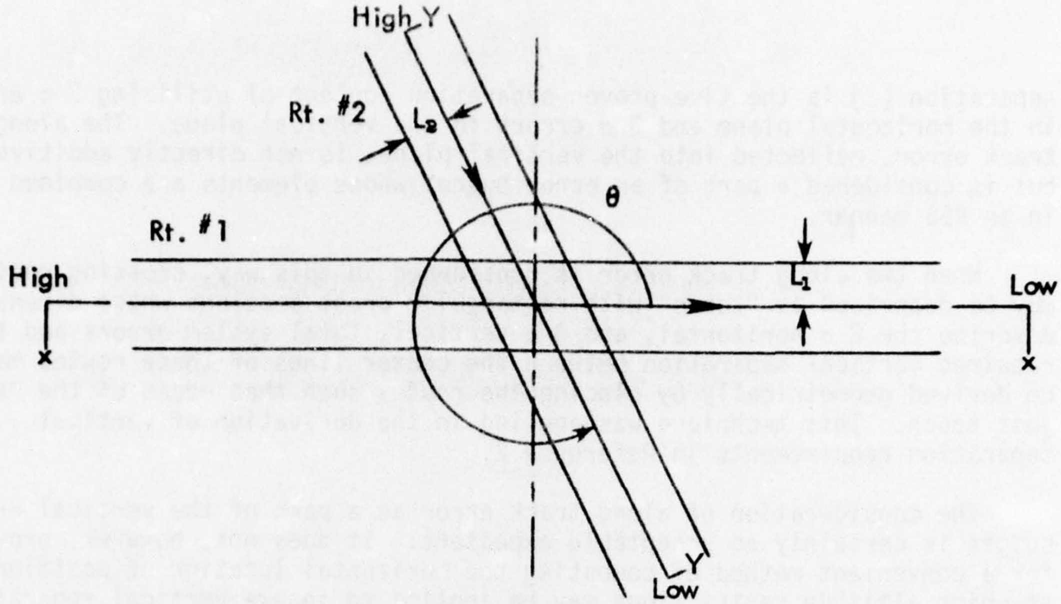


Figure 4.40a Plan View

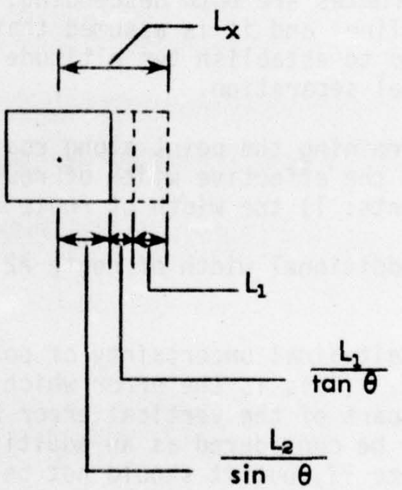


Figure 4.40b Vertical Cross-Section of Route #2 at Intersection

Figure 4.40 Crossing RNAV Routes

track error equal to cross track error is perhaps overly conservative and implies an error distribution which is not wholly representative of any existing RNAV system. Both the inclusion of the maximum along track error in the 2D case, and the RSS combination of the maximum along track error in the 3D case, combine to favor 3D in comparison with 2D separation in the following analysis. However, consideration of any specific postulated error distribution may be accomplished by modifying the along track error terms in the equations which are developed below.

Referring again to Figure 4.40, if L_x is defined as the effective width of route #2, at the intersection of route #1, then for purposes of route separation L_x is as shown in Table 4.19 for various values of the crossing angle θ.

Table 4.19 Effective Width of Crossing Route for Purposes of Altitude Separation

θ = Crossing Angle	L_x = Effective Route Width
$0 < \theta \leq \frac{\pi}{2}$	$\frac{L_1}{\tan\theta} + \frac{L_2}{\sin\theta} + L_1$
$\frac{\pi}{2} < \theta \leq \pi$	$-\frac{L_1}{\tan\theta} + \frac{L_2}{\sin\theta} + L_1$
$\pi < \theta \leq \frac{3\pi}{2}$	$\frac{L_1}{\tan\theta} - \frac{L_2}{\sin\theta} + L_1$
$\frac{3\pi}{2} < \theta \leq 2\pi$	$-\frac{L_1}{\tan\theta} - \frac{L_2}{\sin\theta} + L_1$

Since L_x is zero or positive for all values of θ, L_x may be expressed as:

$$L_x = \left|\frac{L_2}{\sin\theta}\right| + \left|\frac{L_1}{\tan\theta}\right| + L_1 \quad (4.2)$$

and similarly, by inspection:

$$L_y = \left|\frac{L_1}{\sin\theta}\right| + \left|\frac{L_2}{\tan\theta}\right| + L_2 \quad (4.3)$$

The location of altitude restriction points for crossing route separation with an example of altitude restrictions is given in Figure 4.41.

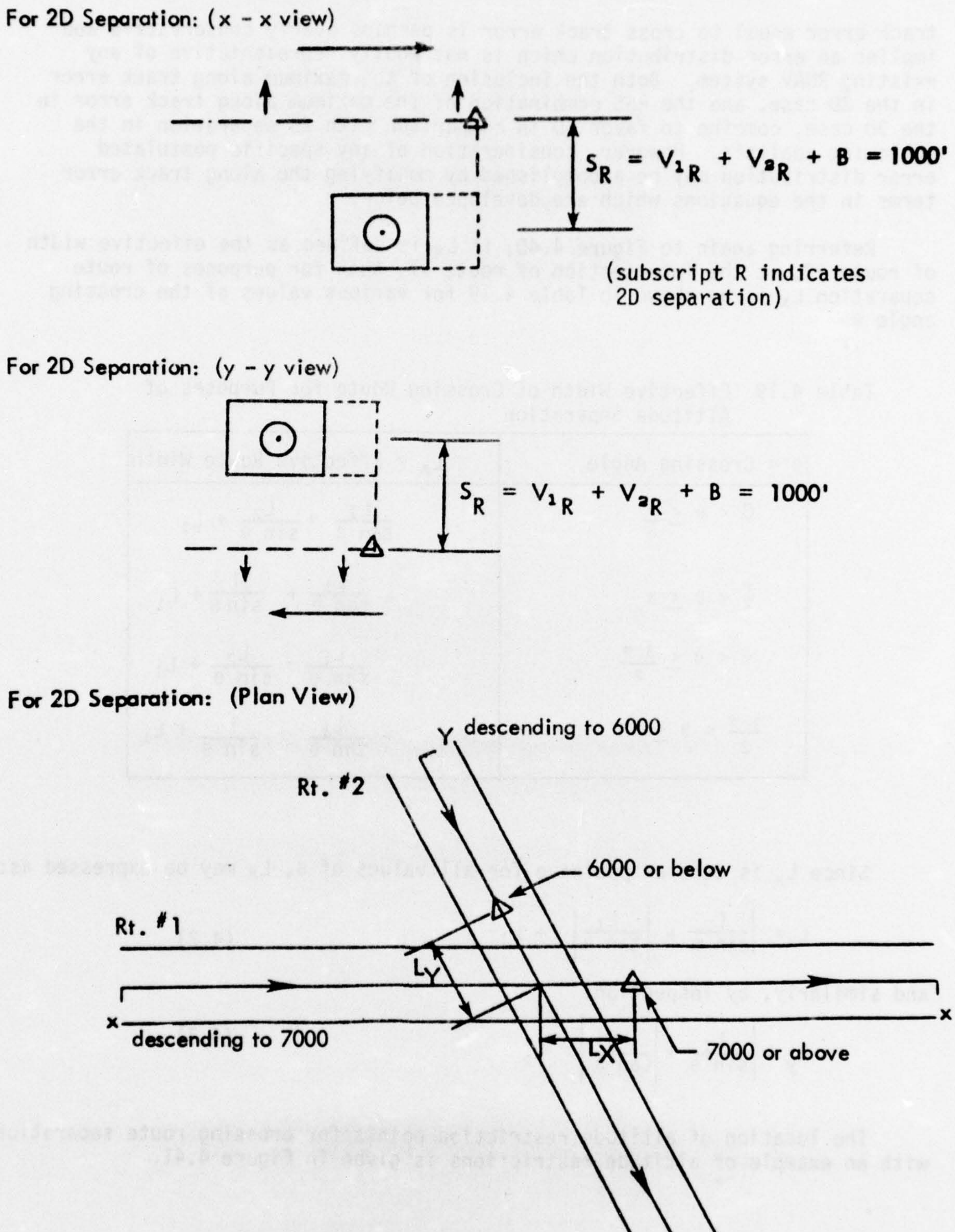


Figure 4.41 2D Separation

A special case of the 2D crossing route situation is depicted in Figure 4.42 where route #1 merges into a route parallel with route #2 at an offset distance of $2L_2$.

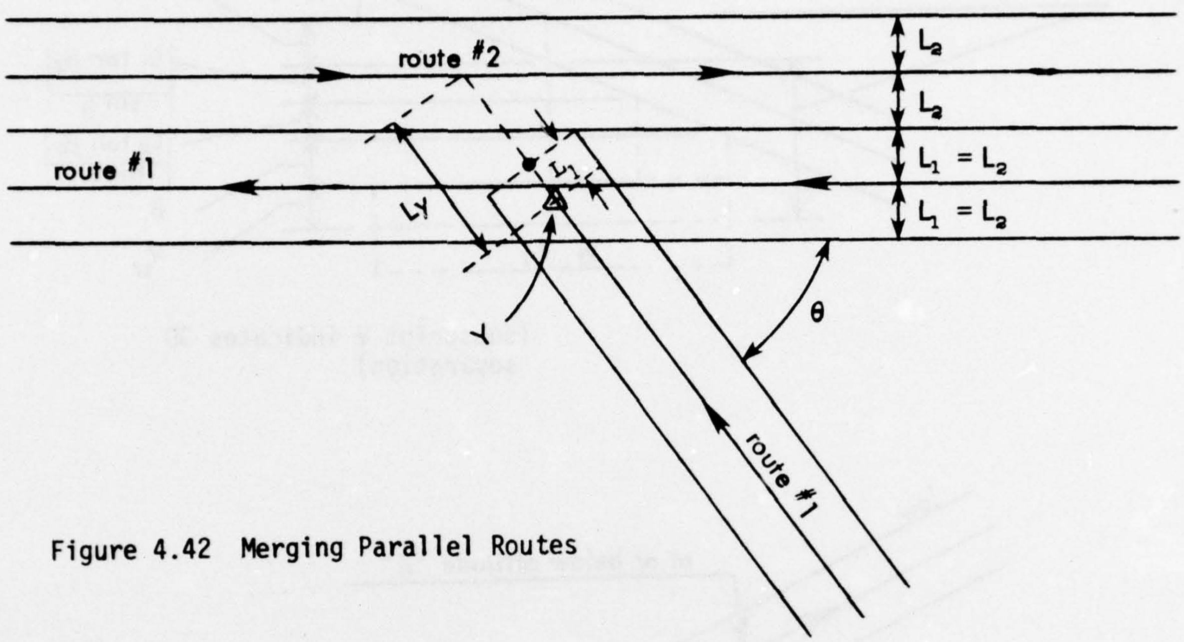


Figure 4.42 Merging Parallel Routes

If route #1 were to continue across route #2 at the angle θ, altitude separation would have to be provided starting at waypoint Y. In the merging case, however, route #1 can be at the same altitude as route #2 since the contribution of along track error on route #1 to parallel offset distance requirements approaches zero as an aircraft makes the turn onto the parallel route, and with some type of turn anticipation the aircraft on route #1 will not violate route #2 airspace (see Section 5.3.3).

4.5.3 2D/3D Separation

Now consider a 3D route (#2) crossing a 2D route (#1) with θ defined such that the high end of route #2 would overlay the high end of route #1 (and the + axis of a right hand coordinate system) when $\theta = 0$, as illustrated in Figure 4.43.

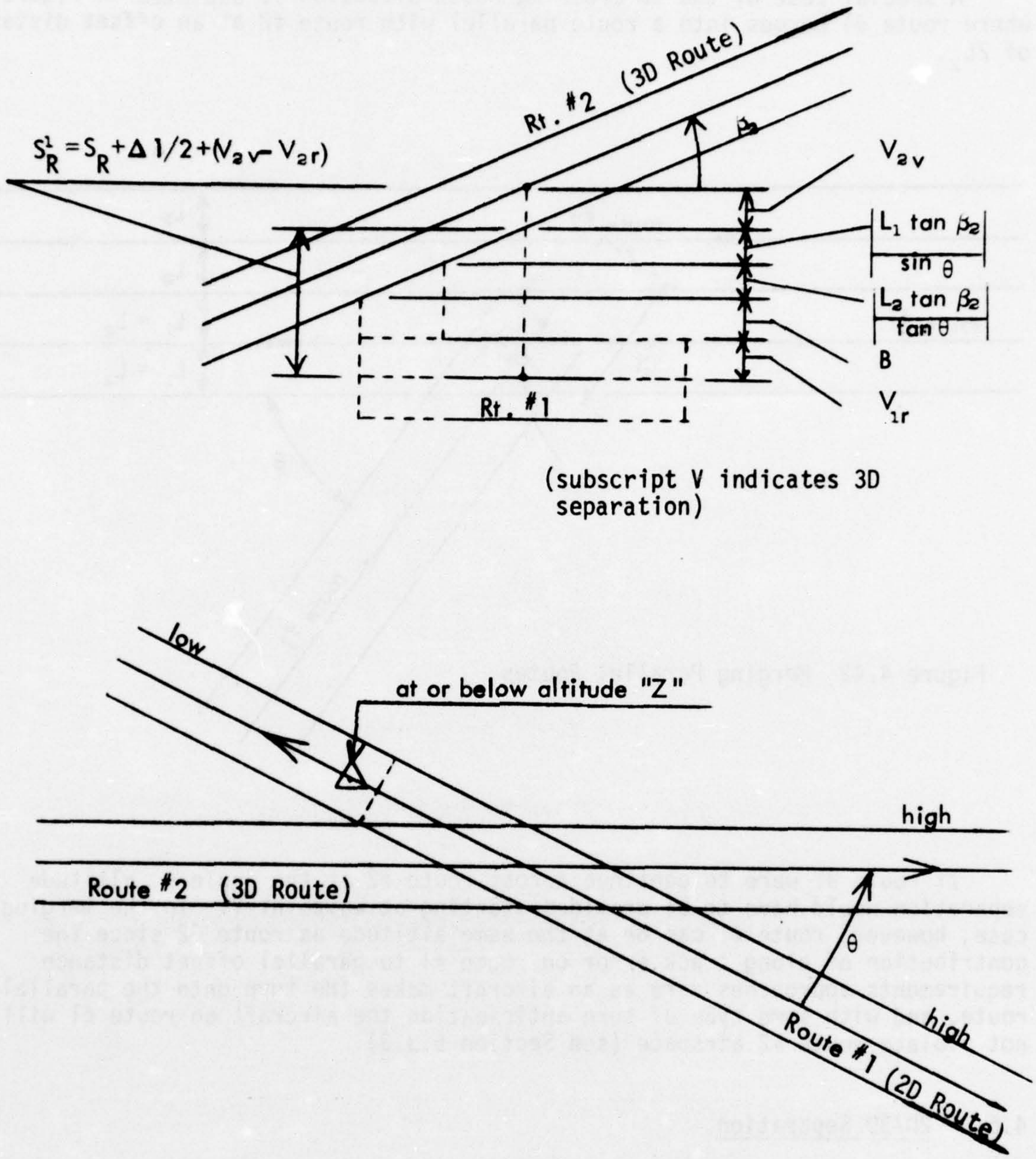


Figure 4.43 2D and 3D Crossing

The vertical separation between the center lines of intersecting 3D routes was derived in Reference 2 and may be expressed as:

$$S = V_1 + V_2 + B + L_1 \left|\frac{\tan \beta_2 - \cos \theta \tan \beta_1}{\sin \theta}\right| + L_2 \left|\frac{\tan \beta_1 - \cos \theta \tan \beta_2}{\sin \theta}\right| \quad (4.4)$$

where $2V_1$ and $2V_2$ are the 3σ vertical dimensions of routes #1 and #2 respectively, B is a "buffer" of 300 ft., and,

$$V = \sqrt{(3\sigma_v)^2 + (3\sigma_{at} \tan \beta)^2} \quad (4.5)$$

In the terminal area, the suggested value for $3\sigma_v$, the error due to altimetry, VNAV equipment, and flight technical error, is ±350 ft. [17]. If a system error budget is assumed which results in a 2σ cross track error of ±2 nm and which includes a 2σ cross track FTE of 1.0 nm, the 3σ along track error reflected into the vertical will be 274 ft. per degree of β.

Then,

$$V = \sqrt{(350)^2 + (274\beta)^2} \quad (4.6)$$

where β is in degrees.

The vertical separation between a 2D and 3D route in the terminal area as illustrated in Figure 4.43 may then be derived from (4.4) with $\beta_1 = 0$, and $V_{1R} = 320$ feet. The altitude Z is defined as the mid point altitude between the centerlines of two crossing routes. (The vertical dimension of a 2D route is slightly less than that of a 3D route with $\beta = 0$, due to VNAV equipment error in the latter). The location of the altitude restriction point on route #1 may then be derived from equation (4.2).

4.5.4 2D vs 3D Altitude Separation

The amount of altitude separation required between crossing routes is a function of crossing angle and vertical path angles for 3D routes and may be several thousand feet. 2D crossing routes require only 1000 feet vertical separation, but the altitude restriction points may be many miles from the intersection along the routes. Consider the 2D crossing routes depicted in Figure 4.44. In cases I through IV and in cases V through VIII the altitude restriction requirements are the same. Altitude separation must be maintained over the entire area of the intersection of the routes, plus a distance equal to the longitudinal uncertainty of position on each route. For acute intersection angles (θ small) an "overlap" of the routes for separation purposes may exist over a horizontal distance of 30 miles or more. The distances from the route intersection to the required altitude restriction point $L_x = L_y$, are given in Table 4.20 for several values of route intersection angle θ for route widths of ±2 nm. Note that the "overlap" given in Table 4.20 is made up the distance due to the intersection of the route widths at the crossing angle θ plus a constant 2 nm longitudinal uncertainty of position.

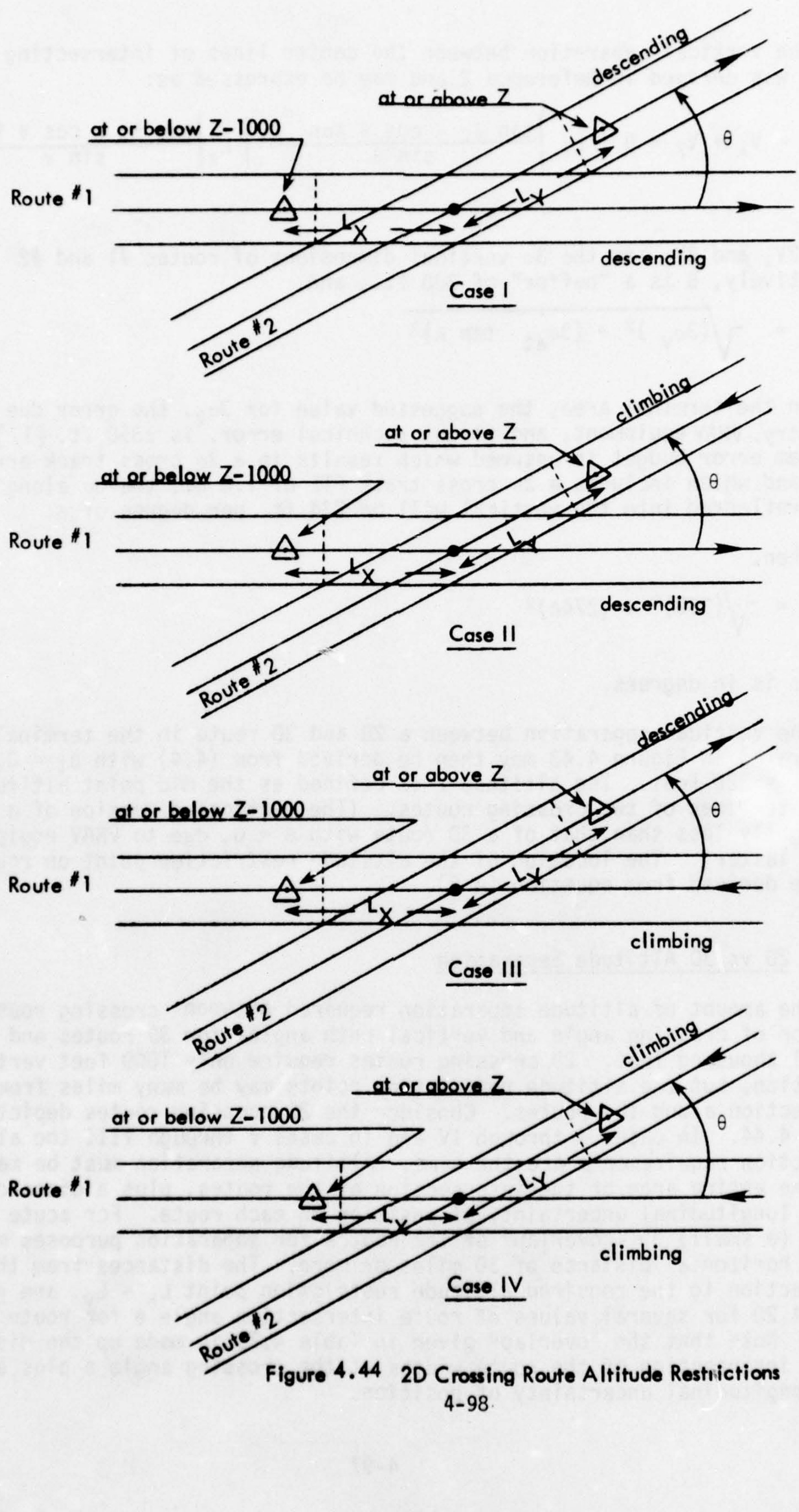


Figure 4.44 2D Crossing Route Altitude Restrictions

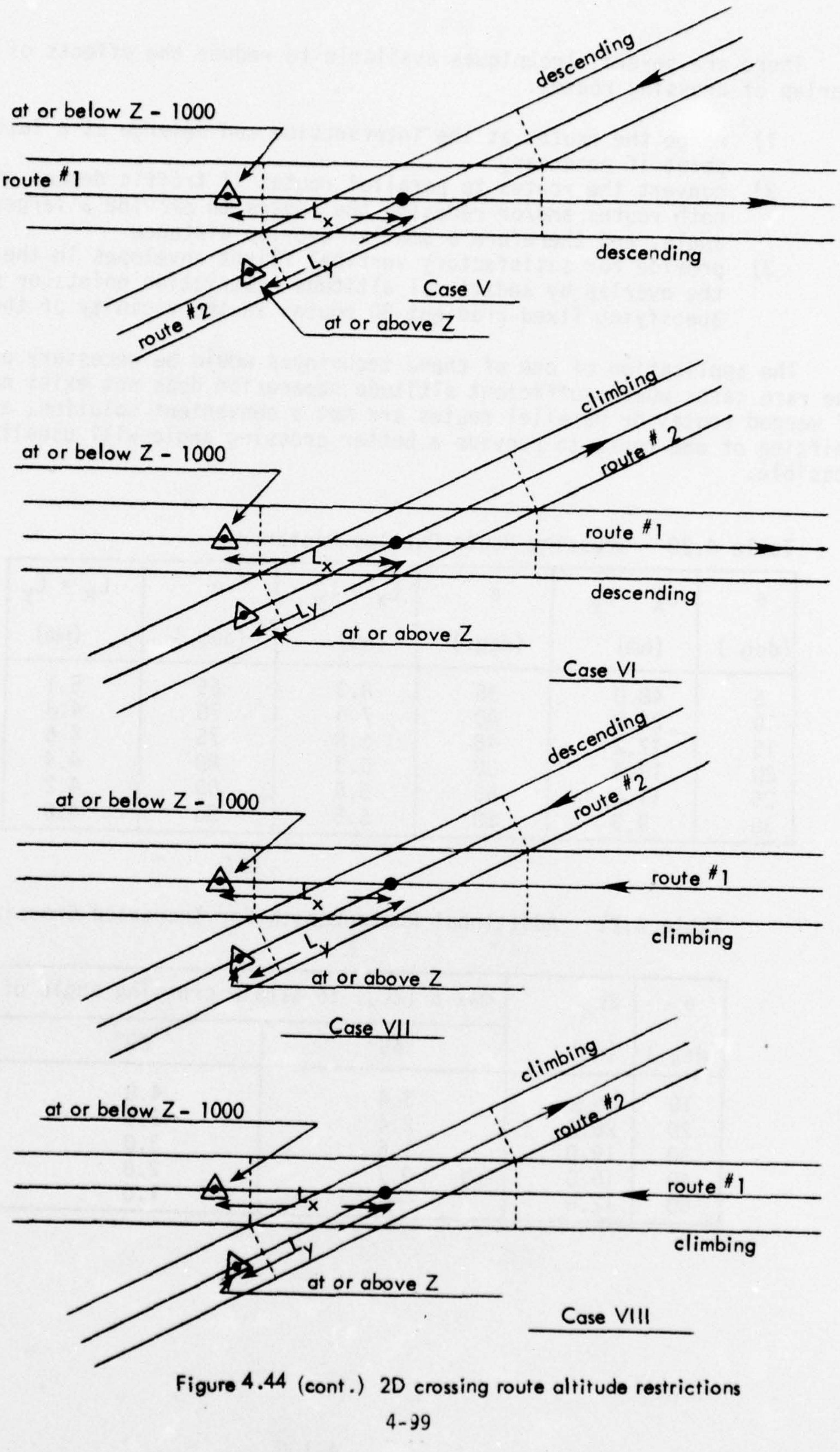


Figure 4.44 (cont.) 2D crossing route altitude restrictions

There are several techniques available to reduce the effects of the overlap of crossing routes:

1) merge the routes at the intersection and demerge at a later point if necessary
2) convert the routes to parallel routes if traffic demand requires both routes and/or redesign the routes to provide a larger crossing angle, and therefore a smaller overlap distance
3) provide for satisfactory vertical flight envelopes in the region of the overlap by additional altitude restriction points or by specifying fixed gradient 3D routes in the vicinity of the intersection

The application of one of these techniques would be necessary only in the rare cases where sufficient altitude separation does not exist naturally. If merged routes or parallel routes are not a convenient solution, a minor shifting of one route to provide a better crossing angle will usually be possible.

Table 4.20 Crossing Route Overlap Distance

θ (deg.)	$L_x = L_y$ (nm)	θ (deg.)	$L_x = L_y$ (nm)	θ (deg.)	$L_x = L_y$ (nm)
5	48.0	35	8.3	65	5.1
10	24.9	40	7.5	70	4.8
15	17.2	45	6.8	75	4.6
20	13.3	50	6.3	80	4.4
25	11.0	55	5.8	85	4.2
30	9.5	60	5.5	90	4.0

Table 4.21 Additional Route Length for Increased Crossing Angles

θ	$2L_x$	max Δ $(2L_x)$ to attain crossing angle of:	
(deg.)	(nm)	45°	60°
10	49.8	3.4	4.8
20	26.6	2.4	3.9
30	19.0	1.6	3.0
40	15.0	0.7	2.0
50	12.6	—	1.0

Table 4.21 gives the maximum additional route length which would have to be added to one route when redesigning that route to increase the crossing angle with another route to a more acceptable value (i.e., 45° - 60°). In the design of seven terminal areas [2], it was found that crossing angle was not a constraint. Minimum crossing angles were usually on the order of 30° between arrival and departure routes, and this angle did not produce vertical separation problems. Arrival routes to multiple airports, which have the potential for small crossing angles, usually are common and are demerged at the appropriate point. Conversely, departure routes are merged prior to the departure waypoints. An increase in route length to improve crossing angles would be a very rare occurrence, and would seldom involve addition of the maximum distance.

The remainder of this subsection addresses the vertical separation required between the centers of crossing fixed gradient 3D (VNAV) routes as compared with the vertical distance between the "effective" centerlines, in the vertical plane, of crossing 2D routes where the vertical path angle (VPA), or "fixed gradient", of the "effective" centerlines are determined by the constraints of altitude restriction points. The latter case is referred to as "2D vertical separation" for convenience in the discussion that follows.

The difference between 2D and 3D vertical separation is illustrated in Figure 4.45. S_V = the vertical separation between 3D routes at the intersection and S_R is defined as the vertical separation which would be required between two 3D routes if 2D (blocked altitude) separation were to be provided instead of 3D separation. Figure 4.45a illustrates VNAV (fixed gradient 3D) crossing routes. Figures 4.45b illustrates the blocked airspace and altitude restriction points for 2D separation. The distance of the altitude restriction points on each route from the intersection of the routes may be derived from Table 4.20. Vertical separation for 3D crossing routes is given by equation[4.4]. The vertical distance between the "effective" centerlines of crossing 2D routes, as illustrated in Figure 4.45b is given by:

$$S_R = \frac{S_{RA}}{2} + \frac{S_{RB}}{2} = L_x \left|\tan \beta_{RA}\right| + L_y \left|\tan \beta_{RB}\right| + 1000 \qquad (4.7)$$

Figure 4.46 gives the vertical separation requirements for 3D intersecting routes, with a constant route width of ±2 nm as a function of crossing angle and vertical path angles. The 2D "separation" as defined above is also given. It should be emphasized that 2D vertical separation can always be reduced to 1000 ft. by shifting one route horizontally to improve the crossing angle and/or allowing the effective maximum vertical path angle to increase on one side of the altitude restriction point and to decrease on the other side. Figure 4.46 applies to the case where it is desired to maintain a 3D ceiling or floor (or minimum or maximum average 2D vertical path angle) which is defined by a straight line between the waypoints defining the respective legs of the routes.

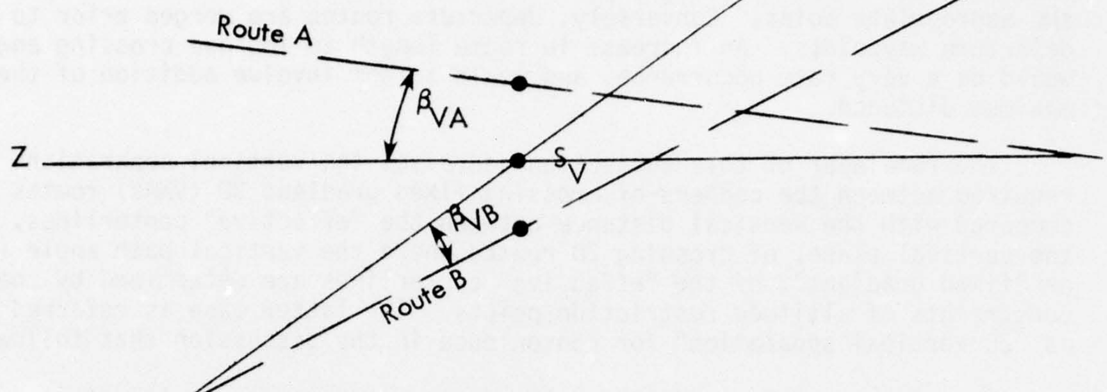


Figure 4.45a Vertical Separation of 3D Routes

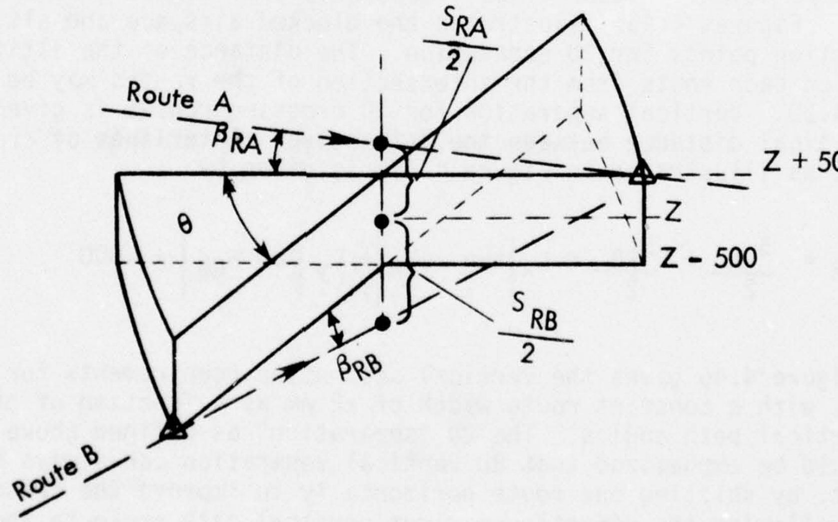


Figure 4.45b. 2D Separation

Figure 4.45 2D and 3D Vertical Separation

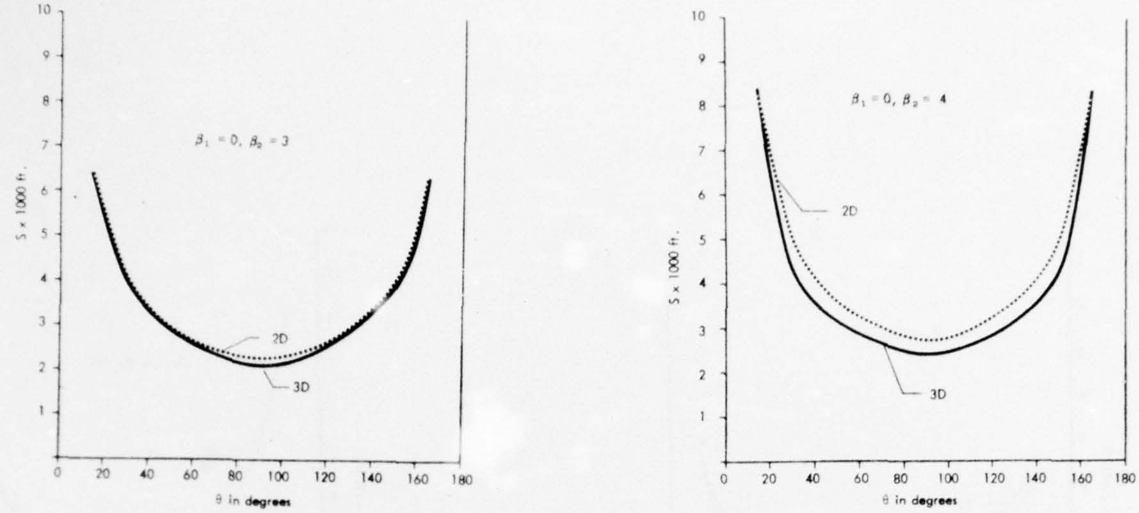


Figure 4.46a

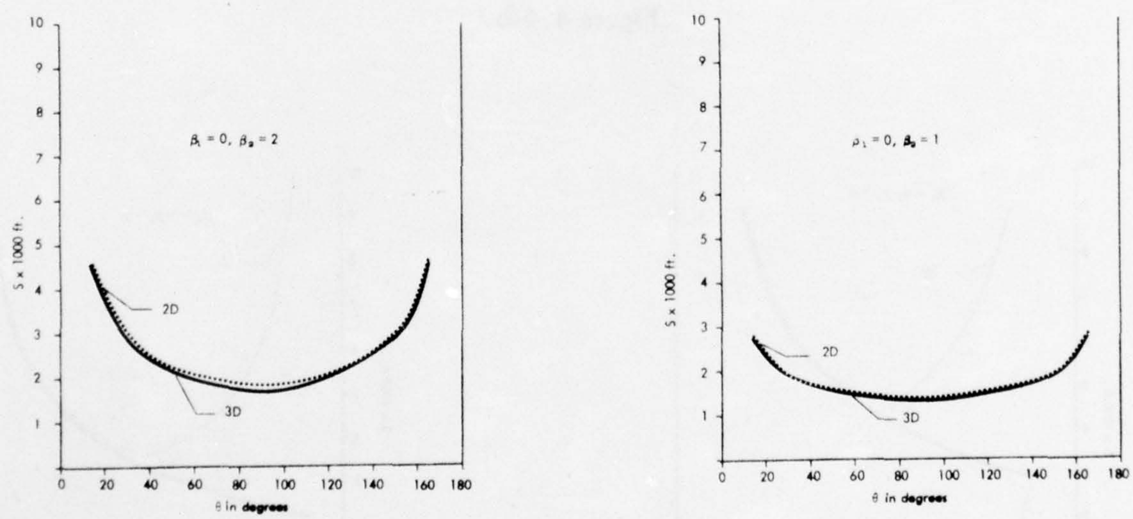


Figure 4.46 2D vs 3D Separation Requirements

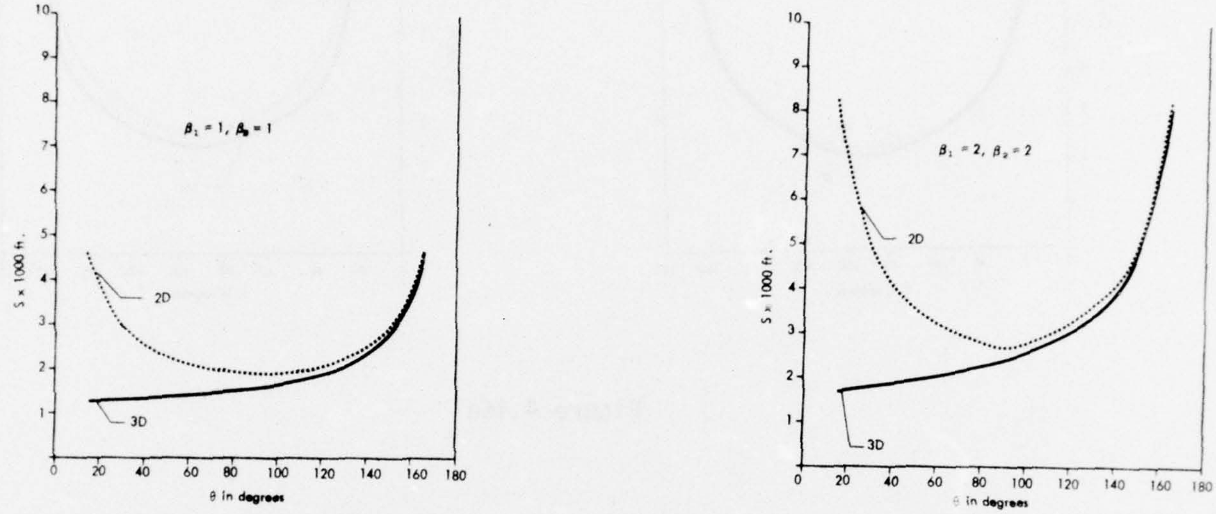


Figure 4.46b

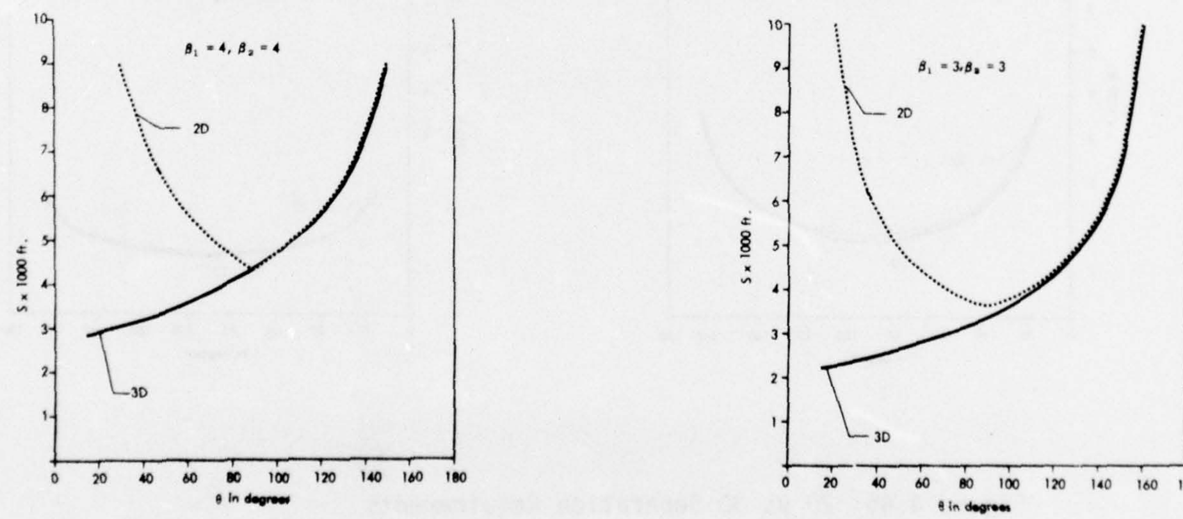


Figure 4.46 (continued) 2D vs 3D Separation Requirements

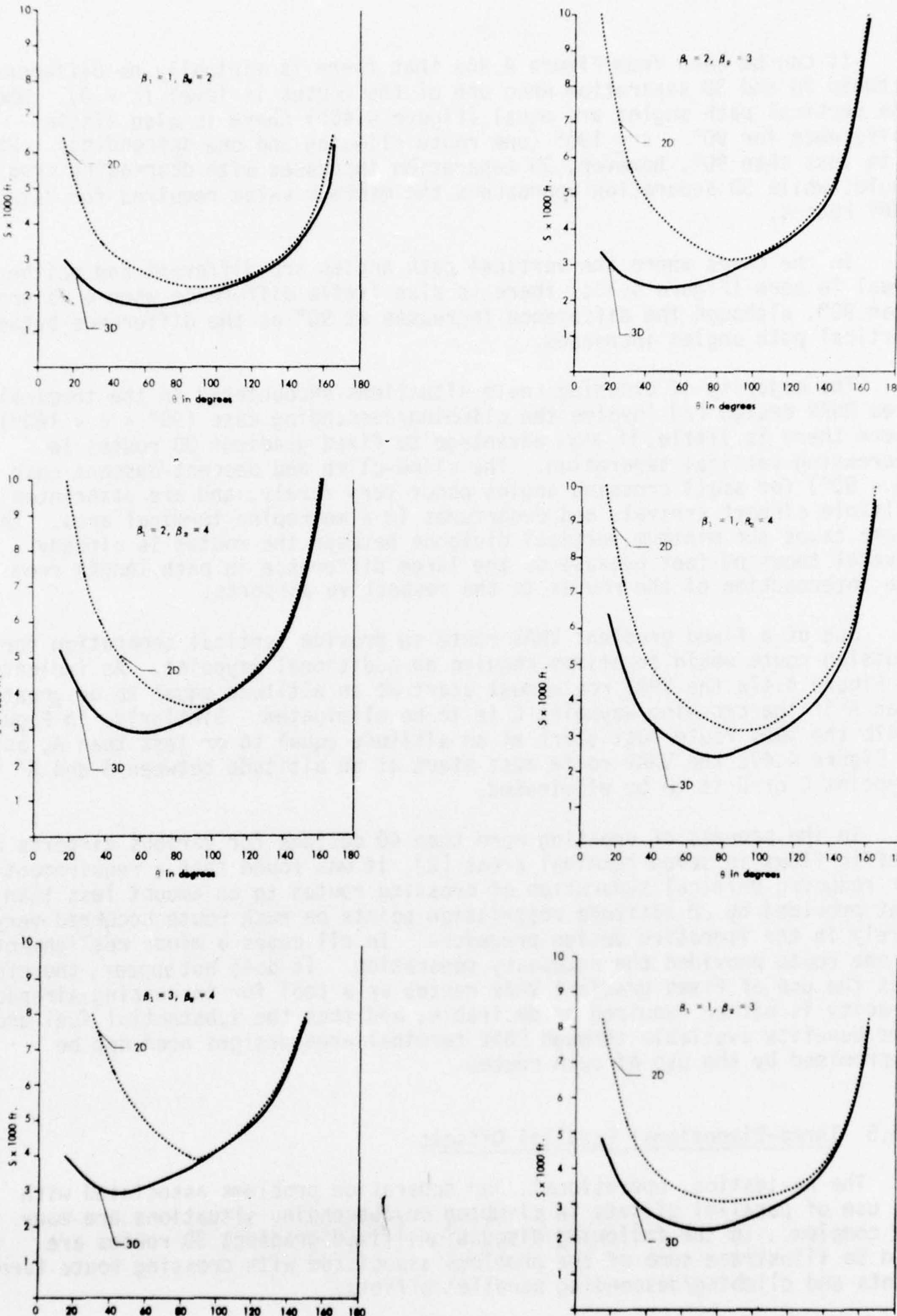


Figure 4.46c

Figure (continued) 2D vs 3D Separation Requirements

It can be seen from Figure 4.46a that there is virtually no difference between 2D and 3D separation when one of the routes is level ($\beta = 0$). When the vertical path angles are equal (Figure 4.46b) there is also little difference for $90° < \theta \leq 180°$ (one route climbing and one descending). When θ is less than 90°, however, 2D separation increases with decreasing crossing angle, while 3D separation approaches the minimum value required for "stacked" VNAV routes.

In the cases where the vertical path angles are different and neither is equal to zero (Figure 4.46c) there is also little difference when θ is greater than 90°, although the difference increases at 90° as the difference between vertical path angles increases.

The majority of crossing route situations encountered in the terminal area RNAV design [2] involve the climbing/descending case ($90° < \theta < 180°$) where there is little, if any, advantage to fixed gradient 3D routes in decreasing vertical separation. The climb-climb and descent-descent case ($\theta < 90°$) for small crossing angles occur very rarely, and are associated with multiple airport arrivals and departures in a metroplex terminal area. In these cases the minimum vertical distance between the routes is already several thousand feet because of the large difference in path length from the intersection of the routes to the respective airports.

Use of a fixed gradient VNAV route to provide vertical separation for a crossing route would sometimes require an additional waypoint. As indicated in Figure 4.47a the VNAV route must start at an altitude equal to or greater than A if the crossing waypoint C is to be eliminated. Similarly, in Figure 4.47b the VNAV route must start at an altitude equal to or less than A, and in Figure 4.47c the VNAV route must start at an altitude between A and A' if waypoint C or D is to be eliminated.

In the process of creating more than 40 designs for various airports and traffic flows in seven terminal areas [2], it was found that a requirement for reducing vertical separation of crossing routes to an amount less than that provided by 2D altitude restriction points on each route occurred very rarely in the iterative design procedure. In all cases a minor realignment of one route provided the necessary separation. It does not appear, therefore, that the use of fixed gradient VNAV routes as a tool for increasing airspace capacity is either required or desirable, and that the substantial fuel and time benefits available through RNAV terminal area designs need not be compromised by the use of such routes.

4.5.5 Three-Dimensional Parallel Offsets

The navigation, operational, and separation problems associated with the use of parallel offsets in climbing or descending situations are many and complex. In the following discussion, fixed gradient 3D routes are used to illustrate some of the problems associated with crossing route turn points and climbing/descending parallel offsets.

3D parallel offsets may be defined with a vertical path angle (VPA) equal to that of the parent route for straight 3D segments. When a 3D

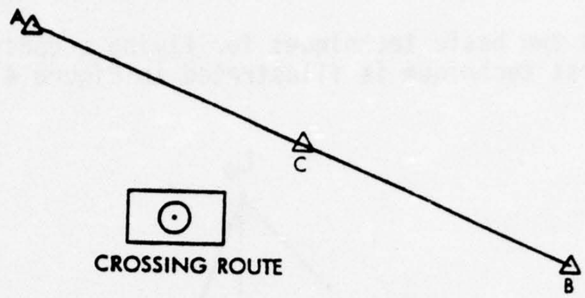


Figure 4.47a

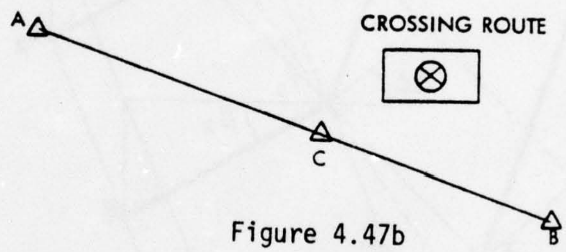


Figure 4.47b

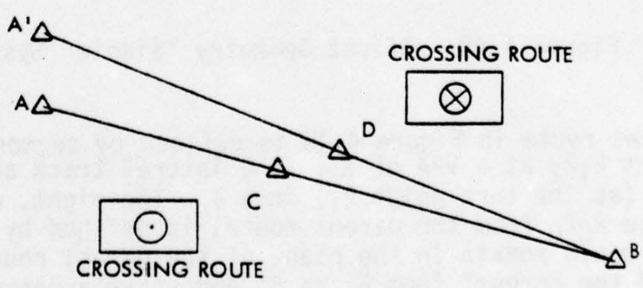


Figure 4.47c

Figure 4.47 Waypoint Requirements for Crossing Fixed Gradient VNAV Routes

segment contains a turnpoint, offset routes with the same VPA as the parent route will experience an altitude discontinuity at the turn point. If this altitude discontinuity is to be avoided, the offset routes must be defined such that they emanate from a point on the bisector of turn angle, with the result that their VPA's differ from the parent route VPA.

There are two basic techniques for flying a constant 3D offset around a turn. The first technique is illustrated in Figure 4.48.

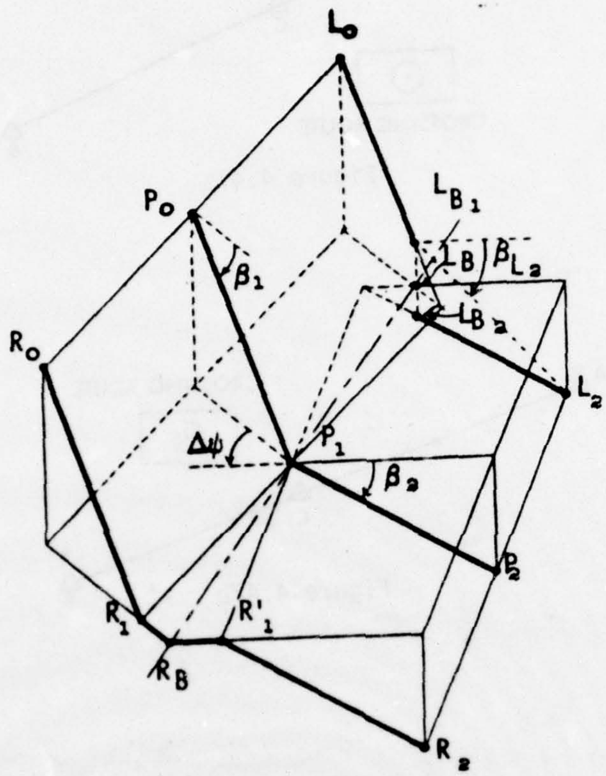


Figure 4.48 Offset Geometry "Simple" System

The parent route in Figure 4.48 is defined by segment P_0P_1 at a VPA of β_1 and by segment P_1P_2 at a VPA of β_2. The lateral track angle from segment P_0P_1 to P_1P_2 (at the turn point P_1) is $\Delta\psi$. The right, or "outside" offset (at a distance R_0P_0 from the parent route) is defined by R_0-R_1-R_B-R_1'-R_2; i.e., the aircraft would remain in the plane of the parent route to point R_1, fly level "around the corner" from R_1 to R_1' and start a descent at a VPA of β_2 at point R_1'. The left, or "inside" offset is defined by L_0-L_{B1}-L_2. When the aircraft reaches the vertical plane through the bisector R_BL_B (which passes

through the intersection of the horizontal projections of segments L_0L_{B1} and L_1L_{B2}) the desired altitude changes instantaneously from L_{B1} to L_{B2} and a minimum VPA of β_{L2} is required to reach point L_2. In other words, an offset on the inside of a turn results in a shorter distance available for the same altitude change, and consequently, a steeper vertical path angle. The VPA of the leg following a turn point for an "inside" offset is plotted in Figure 4.49 for $\beta_1 = \beta_2$.

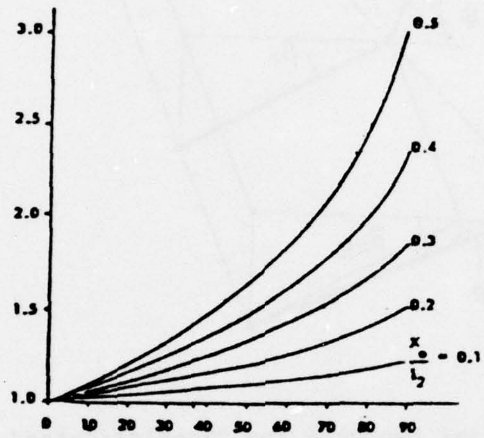


Figure 4.49 Inside Offset VPA

The significance of Figure 4.49 may be illustrated by an example: Consider an aircraft flying on a 6 mile left offset at a vertical path angle, β_1 of -3 degrees. The next leg of the parent route is 20 miles in length, has a VPA, β_2, of -3 degrees and has a track 90 degrees to the left of the present leg.

$\frac{X_0}{\ell_2}$ is then $\frac{6}{20} = 0.3$; entering Figure 4.49 at $\Delta\Psi = 90°$ and $X_0/\ell_2 = 0.3$ gives β_{L_2}/β_2 of 1.85. Upon intercepting the 6 mile left offset of the next leg, the aircraft must attain an average VPA of at least 1.85 x 3 degrees, or 5.55 degrees. The second technique is illustrated in Figure 4.50.

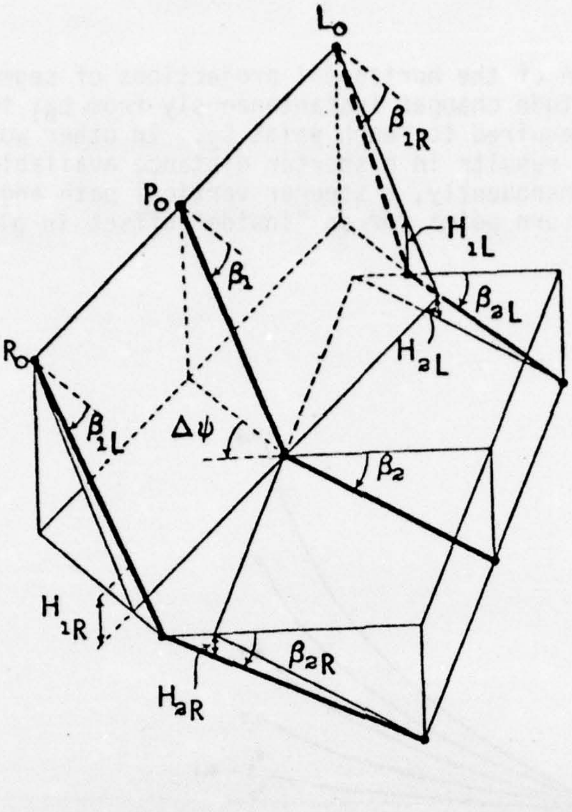


Figure 4.50 Offset Geometry for "Sophisticated" System

In this case, since the offset route turn point is located on the bisector of the angle between adjacent route segments, the length of the second offset is dependent upon the track angle of the third segment, as illustrated in Figure 4.51.

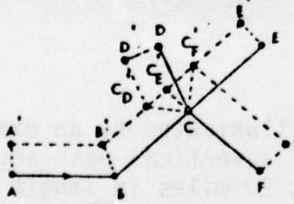


Figure 4.51a

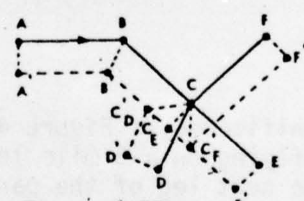


Figure 4.51b

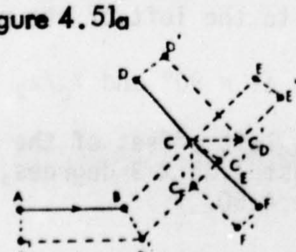


Figure 4.51c

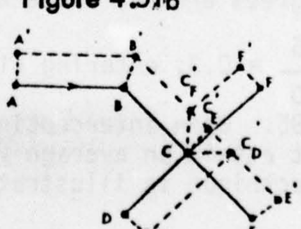


Figure 4.51d

Figure 4.51 Offset Route Horizontal Plan Geometry

In all cases shown in Figure 4.50, the inside offset VPA will be larger than the parent VPA, but the increase required in the VPA will be less than the increase required in the "simple" system technique.

The crossing route vertical separation required for the "simple" system technique illustrated in Figure 4.48 is the same as that required for a straight segment with the following exceptions: 1) the separation above is with respect to leg 1, while the separation below is with respect to leg 2; 2) the effective route width (L) of segments 1 and 2 must include the offset distance.

The crossing route vertical separation required for the "sophisticated" system technique may be greater or less than that for the "simple" system technique, depending upon the geometry of the crossing route situation (see Reference 2 for a detailed discussion).

Figure 4.52 gives the crossing route vertical separation for a straight segment route, B, crossing at the turnpoint of another route, A, with a 6 nm "outside" offset. All conditions are as shown in Figure 4.53, $\beta_A = 3°$; $\beta_B = 0°$, and the length of leg 2 of route A is 25 nm. The geometry is as depicted in Figure 4.51c, configuration ABCE.

An example is illustrated on Figure 4.52. The specific geometry depicted in Figure 4.53 would require vertical separation between the route centerlines at the crossing point X of approximately 2400 feet for route B crossing above, and 2600 feet for route B crossing below route A.

If the "simple" system technique (Figure 4.48) were used by all aircraft on route A offset, their altitude at point X' (Figure 4.53) would be the same as at point X and no additional separation would be required above that required between route B and leg 1 of route A for route B crossing over route A. Likewise, the altitudes at point X and X' would be the same, and the separation required for route B to cross below route A would be the same, and the separation required for route B to cross below route A would be determined by the crossing angle between route B and leg 2 of route A.

4.5.6 Vertical Separation for Pilot-Selected 3D Routes

Figure 4.46 shows a comparison of the required separation between crossing VNAV routes and the vertical distance between the "effective" centerline of crossing 2D routes. The "effective" gradient of a 2D route may also be defined as a pilot-selected fixed gradient to or from the 2D altitude restriction point. It can be seen from Figure 4.46 that the actual separation of pilot-selected 3D gradient, as indicated by the dashed lines, when passing through the 2D altitude restriction points is always greater than, or equal to, the required vertical separation, as shown by the solid lines, for combinations of vertical path angles up to 4 degrees.

This section further analyzes the vertical separation provided between pilot-selected 3D routes which are based on altitude restriction points established for 2D separation.

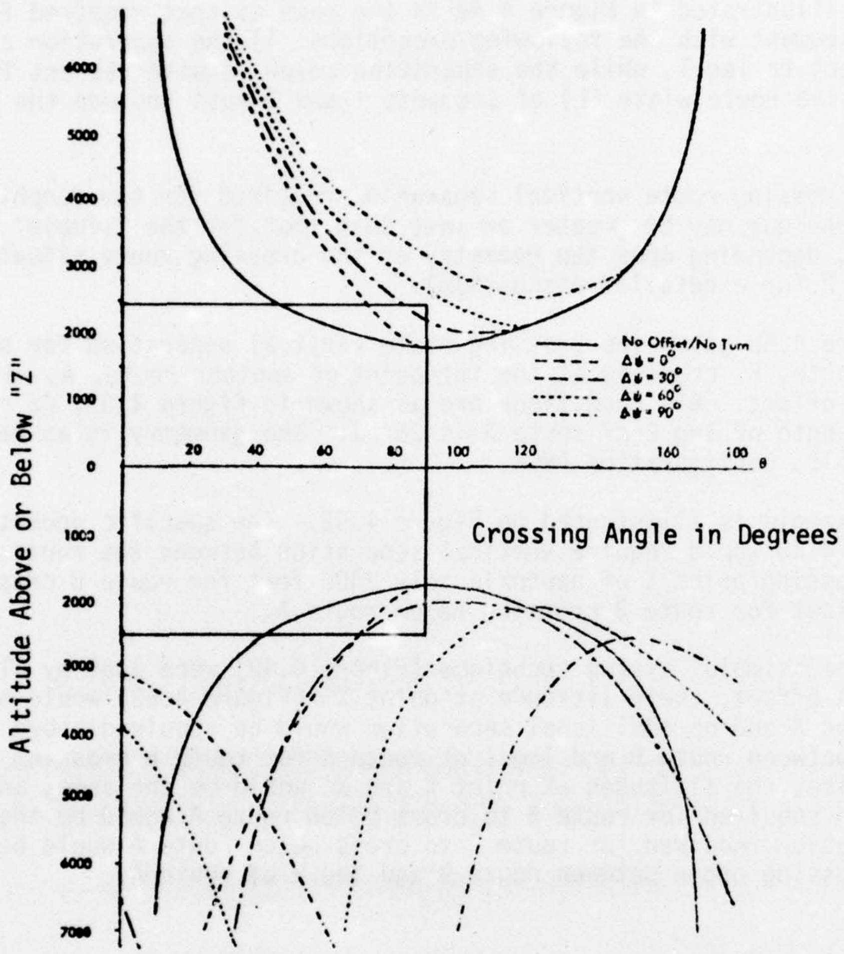


Figure 4.52 Vertical Separation for Turning Routes - "Sophisticated" System (6nm offset, 25nm legs)

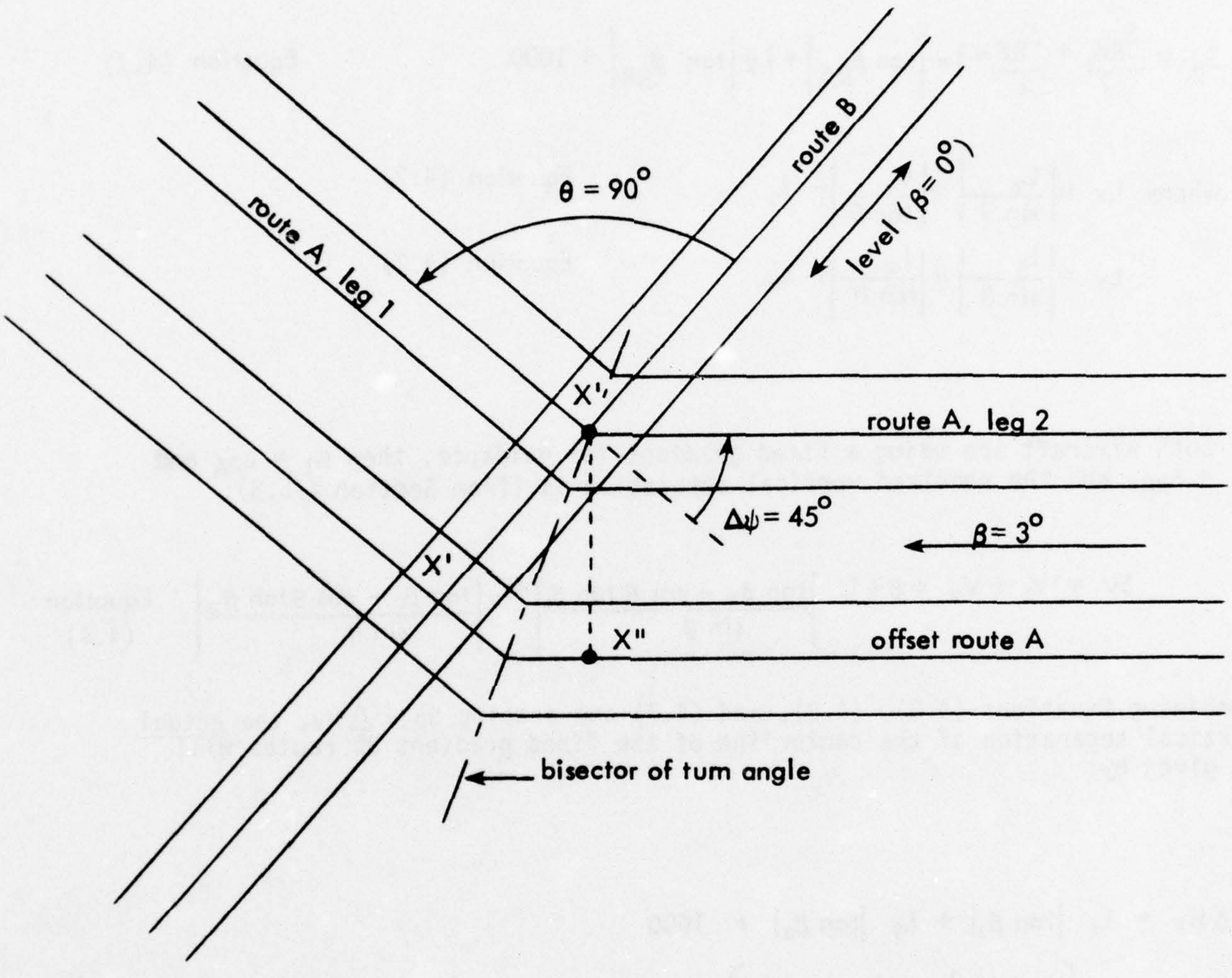


Figure 4.53
Projection of Crossing Routes in Horizontal Plane

In Section 4.5.4, it was shown that the vertical distance between the "effective" centerlines of crossing 2D routes (or of pilot-selected gradients), is given by the following equation:

$$S_R = \frac{S_{RA}}{2} + \frac{S_{RB}}{2} = L_x \left|\tan \beta_{RA}\right| + L_y \left|\tan \beta_{RB}\right| + 1000 \qquad \text{Equation (4.7)}$$

where
$$L_x = \left|\frac{L_2}{\sin\theta}\right| + \left|\frac{L_1}{\tan\theta}\right| + L_1 \qquad \text{Equation (4.2)}$$

$$L_y = \left|\frac{L_1}{\sin\theta}\right| + \left|\frac{L_2}{\tan\theta}\right| + L_2 \qquad \text{Equation (4.3)}$$

If both aircraft are using a fixed gradient for guidance, then $\beta_1 = \beta_{RA}$ and $\beta_2 = \beta_{RB}$, and the required vertical separation is (from Section 4.5.3):

$$S_v = V_1 + V_2 + B + L_1 \left|\frac{\tan\beta_2 - \cos\theta\tan\beta_1}{\sin\theta}\right| + L_2 \left|\frac{\tan\beta_1 - \cos\theta\tan\beta_2}{\sin\theta}\right| \qquad \text{Equation (4.4)}$$

Combining Equations (4.2), (4.3), and (4.7) and setting $S_R = \Delta H_v$, the actual vertical separation of the centerline of the fixed gradient 3D routes will be given by:

$$\begin{aligned}\Delta H_v = {} & L_1 \left|\tan\beta_1\right| + L_2 \left|\tan\beta_2\right| + 1000 \\ & + L_1 \left\{\frac{\left|\tan\beta_1\right| \left|\cos\theta\right| + \left|\tan\beta_2\right|}{\left|\sin\theta\right|}\right\} \\ & + L_2 \left\{\frac{\left|\tan\beta_2\right| \left|\cos\theta\right| + \left|\tan\beta_1\right|}{\left|\sin\theta\right|}\right\} \qquad \text{Equation (4.8)}\end{aligned}$$

by definition, β_1 and β_2 are positive; therefore, for $0 \leq \theta \leq \frac{\pi}{2}$,

$$\frac{|\tan \beta_2 \cos \theta| + |\tan \beta_1|}{|\sin \theta|} \geq \left| \frac{\tan \beta_1 - \cos \theta \tan \beta_2}{\sin \theta} \right|$$

and
$$\frac{|\tan \beta_1 \cos \theta| + |\tan \beta_2|}{|\sin \theta|} \geq \left| \frac{\tan \beta_2 - \cos \theta \tan \beta_1}{\sin \theta} \right|$$

also, for $\frac{\pi}{2} \leq \theta \leq \pi$,

$$\frac{|\tan \beta_2 \cos \theta| + |\tan \beta_1|}{|\sin \theta|} = \left| \frac{\tan \beta_1 - \cos \theta \tan \beta_2}{\sin \theta} \right|$$

and
$$\frac{|\tan \beta_1 \cos \theta| + |\tan \beta_2|}{|\sin \theta|} = \left| \frac{\tan \beta_2 - \cos \theta \tan \beta_1}{\sin \theta} \right|$$

By comparing equation (4.4) with equation (4.8), it can be seen that Δ Hv will always be equal to or larger than Sv if:

$$L_1 |\tan \beta_1| + L_2 |\tan \beta_2| + 1000 \geq V_1 + V_2 + B$$

Let $\Delta S = \Delta Hv - Sv$ and $B = 300$ ft.

then $\Delta S = L_1 |\tan \beta_1| + L_2 |\tan \beta_2| + 700 - V_1 - V_2$ Equation (4.9)

Figure 4.54 is a plot of ΔS_{min} vs β_1 and β_2 for the following conditions (reference Equation (4.6):

$$L_1 = L_2 = 2 \text{ nm}$$

$$V_1 \approx \sqrt{(350)^2 + (274 \beta_1)^2}$$

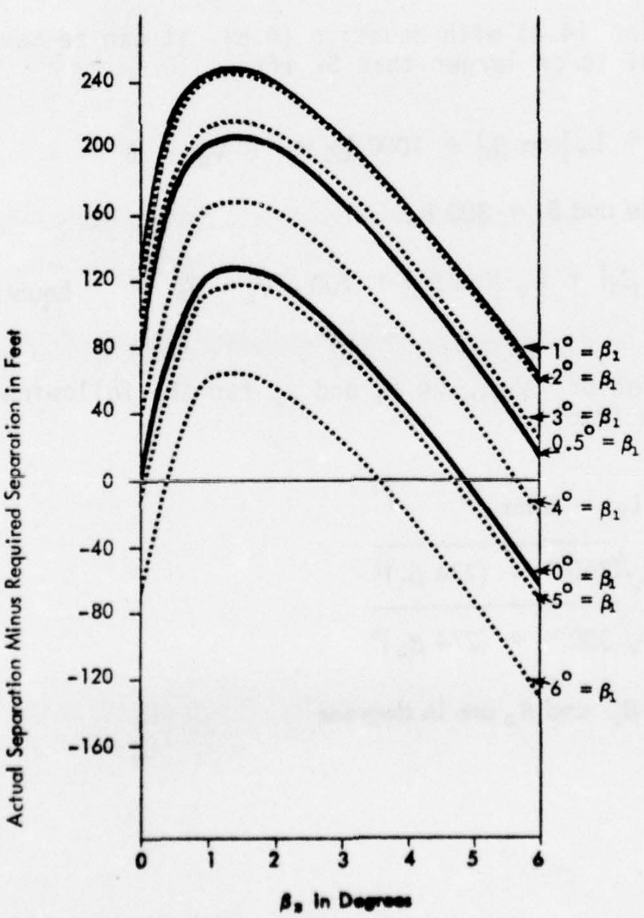
$$V_2 = \sqrt{(350)^2 + (274 \beta_2)^2}$$

where β_1 and β_2 are in degrees

The separation buffer shown in Figure 4.54 is the minimum buffer that will exist, independent of the crossing angle of the routes for $0 \leq \theta \leq \frac{\pi}{2}$, and is the actual buffer that will exist for $\frac{\pi}{2} \leq \theta \leq \pi$. If both routes are climbing or both routes are descending ($0 \leq \theta \leq \frac{\pi}{2}$) and $\theta \leq 87°$ the separation buffer will always be greater than zero for combinations of $0 \leq \beta_1 \leq 6°$ and $0 \leq \beta_2 \leq 6°$. If one route is climbing and the other route descending ($\frac{\pi}{2} \leq \theta \leq \pi$), the altitude restriction points must be placed 0.2 nm further from the route intersection to insure vertical separation between pilot-selected combinations of fixed gradient routes up to 6 degrees.

Figure 4.54

Minimum Vertical Separation Buffer - Actual Vertical Separation vs Required Vertical Separation for Pilot-Selected 3D Gradient to 2D Altitude Restriction Point



5.0 RNAV PAYOFF SUMMARY AND OPERATIONAL CONCEPT

The preliminary analyses of ATC system and user impact reported in References 11 and 12 have been updated and expanded as described in Sections 3 and 4 of this report. The results of these analyses as well as those of other supporting system analyses, described in Section 2.1, have a significant impact on the system design concept recommended by the RNAV Task Force. In Sections 5.1 and 5.2 below, the results of these studies are summarized and discussed in this context as a prelude to the development of a modified Task Force system design concept in Section 5.3 and the resulting implementation requirements described in Section 5.4. The impacts shown in this section apply to an all-RNAV environment. However, significant individual aircraft benefits are available to equipped aircraft as RNAV routes are implemented in the transition phases. The system concept which is defined includes a phased transition from VOR to RNAV, such as suggested by the Task Force, but the timing of the phases is dependent upon user demand rather than the fixed calendar periods recommended by the Task Force.

5.1 USER IMPACT SUMMARY

This section presents a summary of user benefits which will accrue through the use of 2D, 3D and 4D RNAV and 2D/3D approach procedures. The annual savings which can be expected to accrue to air carriers, business and other general aviation are listed, and the corresponding cost impact on both civil and military users of the National Airspace System is discussed.

5.1.1 <u>Terminal Area Benefits</u>

5.1.1.1 2D RNAV Benefits

In previous studies [9,12], it was determined that the dominant factors relative to their impact on user operations in the terminal area are route length and altitude restriction reductions. These benefits were attained by the development of a flexible RNAV design concept which represents a modification of the RNAV Task Force design concept. This terminal area design concept is summarized in Section 5.3.1.2 and described in detail in Reference 2. The fuel and time savings in an RNAV terminal area compared with current VOR/radar vector routes are derived in Section 3.1 for eight different types of aircraft for each traffic flow at nine major airports. The benefits at these airports were used to extrapolate the benefits to the sixty high and medium density airports including those identified in the Task Force Report [1]. The extrapolation was accomplished by applying a regression analysis to the nine airport data base for use in estimating the sixty airport benefits as a function of terminal area characteristics.

Table 5.1 summarizes fuel and time savings at 1984 traffic levels for 2D RNAV operations at the 60 major airports compared with VOR/vector operations. Estimates for business piston aircraft and other general aviation aircraft are based on average distance saved at six of the airports studied (New York was excluded because of the uniqueness of its characteristics).

Table 5.1 2D RNAV Fuel and Time Savings at 60 Major Airports 1984 Traffic Levels

	Fuel Savings (1000 lb)	Time Savings (1000 min)
Certificated Air Carrier Aircraft		
4 engine wide body	140,697	394
3 engine wide body	226,941	951
4 engine jet	59,423	288
3 engine jet	301,662	2,172
2 engine jet	267,252	1.930
Total Air Carrier	995,975	5,735
Business aircraft -		
Jets & Turboprops	2,167	91
Piston Aircraft	1,638	1,023
Total Business Aircraft	3,805	1,114
Other General Aviation Aircraft	8,923	5,574
TOTAL	1,008,703	12,423

The average distance saved was computed to be 2.16 miles per operation, based on the data given in Table 3.1. From data given in Reference 33, it was estimated that the average speed of general aviation piston aircraft is 120 mph and their average fuel consumption is 0.8 lb per mile. The average fuel and time savings per operation (1.73 lb and 1.08 minutes) was then applied to general aviation itinerant operations in 1984. From NBAA data it was estimated that 14.75% of GA itinerant operations are business piston flights, in addition to the 4.85% business jet and turboprop operations. The remaining 80.4% are categorized as "other general aviation". Total general aviation itinerant operations at the sixty airports was estimated to be 6,419,000 [21]. Results of real time simulations of the New York terminal area [9,11] confirmed that the distance savings are available in an operational environment and are not reduced by the requirements for traffic sequencing. The results of the real time simulation described in reference 11 further indicated a substantial reduction in arrival delays (an average of 4.7 minutes per arrival) which would result in time and fuel savings in addition to those shown in Table 5.1. The simulation also showed that an additional distance savings resulted, over and above that attributed to design efficiency. VOR and RNAV traffic was all flown over the RNAV routes in the simulation, with VOR traffic navigated by radar vectors and RNAV traffic self-navigated. On the average, the RNAV equipped aircraft flew 1.61 miles less than non-RNAV aircraft, and had a corresponding time savings of 1.02 minutes. These benefits

are in addition to the fuel and time benefits (in the New York terminal area) which are realized by better altitude profiles and the average distance savings of 11.6 miles per operation which are due to the improved design efficiency of the RNAV design compared with current day VOR/vector routes.

From Tables 3.3 and 3.4, it can be seen that 190 million pounds of fuel and 914,000 minutes are projected to be saved over a total of 337,000 airline and business jet operations at JFK in 1984 through 2D RNAV due to improvement in the terminal area design by RNAV. Additional savings of 112 million pounds of fuel and 964,000 minutes can be expected to be saved through reduction in arrival delays and better adherence to designated terminal area routes. The 2D benefits at JFK then consist of those due to strategic design efficiency (which are included in the aggregate TMA benefits shown in Table 5.1) plus additional benefits of the same order of magnitude which result from improvement in tactical efficiency. It may be assumed that this improvement in tactical efficiency is related to both design complexity and traffic levels. Since the simulation was conducted only for the JFK design, no basis exists to extrapolate these additional savings to other terminal areas. It can be reasonably concluded, however, that overall tactical savings in the terminal area can be expected, and their magnitude is of the order of a significant percentage of the strategic savings.

5.1.1.2 3D Descent Benefits

Additional benefits available through the use of pilot-selected 3D descents at the 60 major airports were computed for certificated air carrier aircraft in Section 3.1.3, and are summarized in Table 5.2.

Table 5.2 Fuel and Time Savings Available From Air Carrier Pilot-Selected 3D Descents at 60 Major Airports at 1984 Traffic Levels

	Fuel Savings (1000 lb)	Time Savings (1000 min.)
4 engine wide body	23,000	54
3 engine wide body	69,900	300
4 engine jet	34,100	142
3 engine jet	168,500	1,150
2 engine jet	181,300	1,668
Total Air Carrier	476,800	3,314

The penalties in fuel and time which would be incurred in fixed gradient 3D climbs are given in Reference 12. No penalties for 3D climbs are anticipated since the terminal area design concept described in Section 5.3 provides for essentially unrestricted climbs through use of high performance climb envelopes. The benefits due to these envelopes are included in the 2D savings summarized in Section 5.1.1.1.

5.1.1.3 4D Benefits in M & S Terminals

Section 4 presents an analysis of the impact of 4D RNAV capability on arrival delays through a comparison of 4D RNAV time-control with presently planned metering and spacing automation improvements. Results of analytical studies and simulations have shown that 4D RNAV techniques may be employed in M & S terminals to significantly reduce arrival control error in comparison with the control error expected with metering and spacing alone. The analysis in Section 4 determines the runway capacity increase and corresponding reduction in delays which result from the reduction of interarrival control error with 4D RNAV in M & S terminals.

The time savings at the 25 major delay terminals in 1984 that can be realized with 4D navigation in addition to metering and spacing, which were derived in Section 3.4, were used to estimate the corresponding fuel savings. The average holding fuel flow for the five types of air carrier aircraft was derived on the basis of the 1984 projected fleet mix in Table 5.6 and applied to the total time savings. Total 4D savings in 25 M & S terminals are given in Table 5.3.

Table 5.3 Fuel and Time Savings through 4D in 25 Major M & S Terminals

	Fuel (1000 lb)	Time (1000 min.)
Air Carrier Aircraft	980,370	9,044

5.1.1.4 RNAV Approach Benefits

Area navigation has already found widespread use in instrument approach procedures. (More than 200 2D RNAV approaches have been requested by users and published to date.) RNAV approaches offer flexibility in selection of obstacle-free approach paths. An RNAV approach which is based on VOR/DME inputs cannot inherently have lower circling minimums than a VOR/DME approach, since it is subject to the same navigational errors (plus RNAV computer error), but it may be possible to establish a straight-in approach to a runway where only a circling approach is possible with VOR or VOR/DME procedures. The additional flexibility available from RNAV approaches is due to the capability to define approach paths which are not constrained to VOR radials or DME arcs. An analysis was made of 206 published RNAV approach procedures compared with other types of approaches published for the same runways. The differences in Minimum Descent Altitude (MDA) or Decision Height (DH) between the RNAV approaches and the corresponding VOR, VOR/DME, NDB, ASR, or ILS approaches to the same runways are summarized in Table 5.4 and are plotted for each comparison in Figure 5.1. The bars in Figure 5.1 represent a range of MDA differences on the horizontal areas and the number of the differences in that range on the left vertical axis represents an RNAV MDA lower than VOR/DME. The dashed lines on Figure 5.1 are the cumulative number of RNAV MDAs which are "X" better than VOR/DME, as read on the right vertical axis.

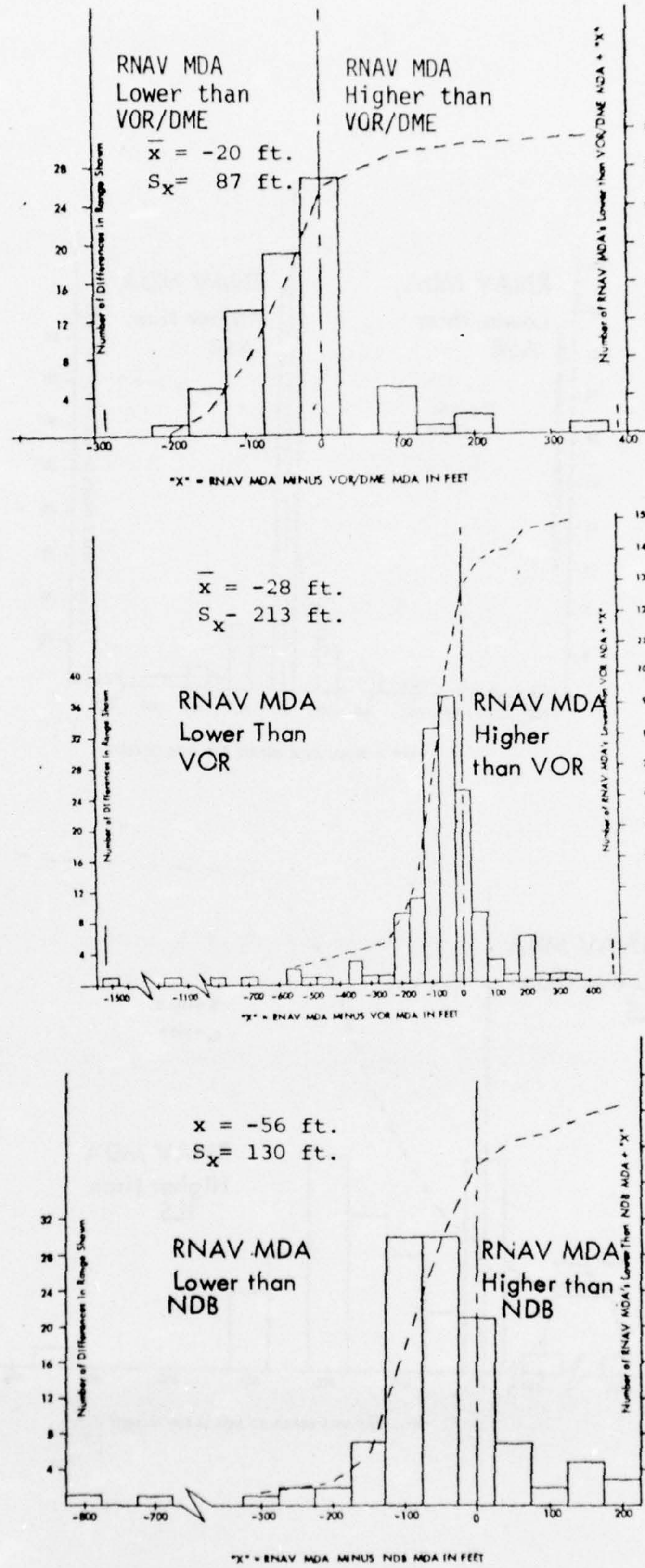
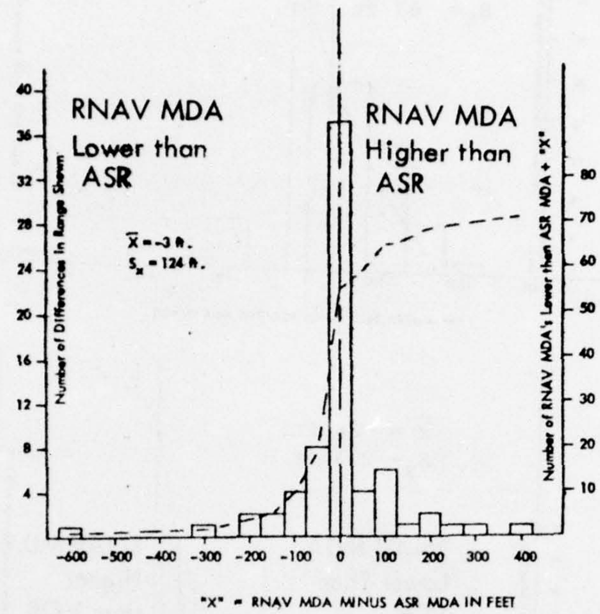


Figure 5.1 Comparison of RNAV MDA With Other Approach Minimums



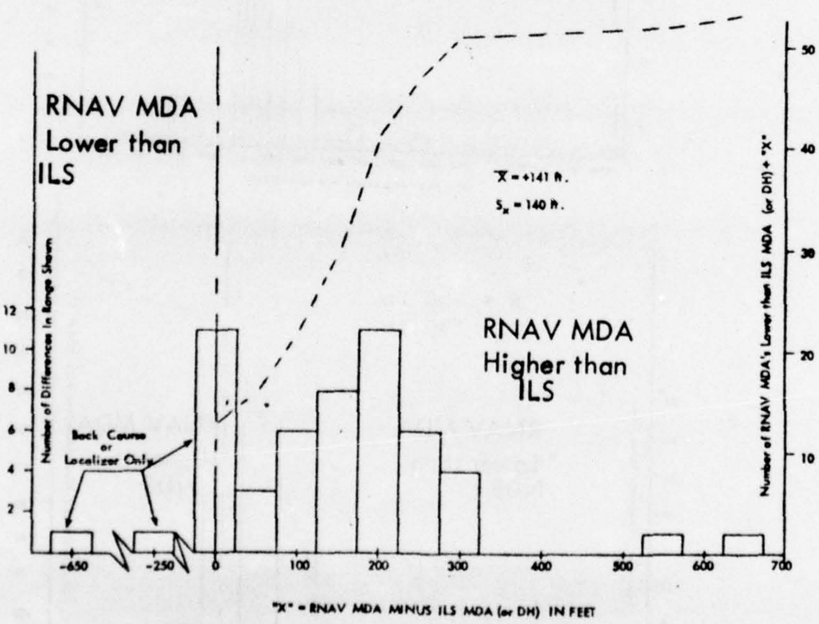
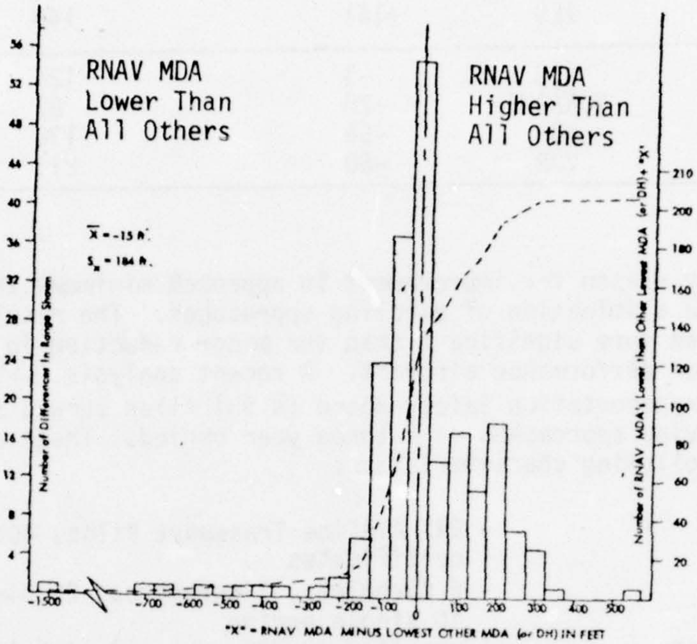


Figure 5.1 Comparison of RNAV MDA With Other Approach Minimums (continued)



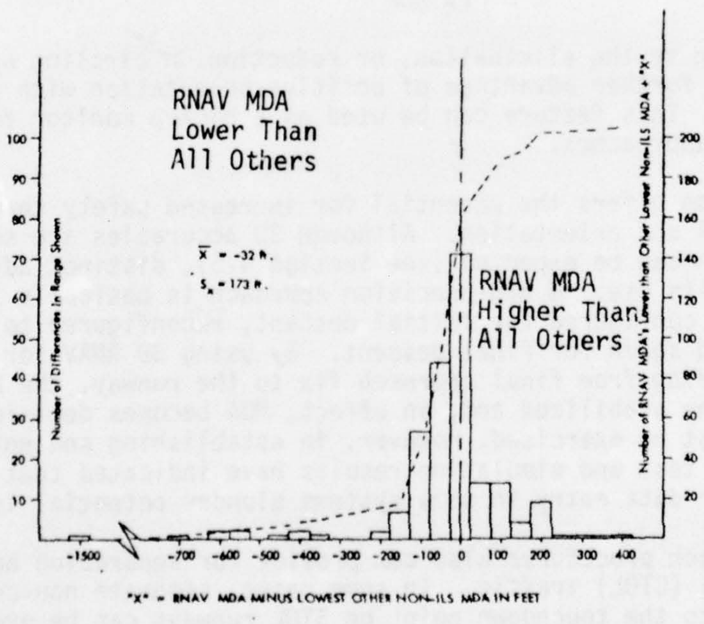


Figure 5.1 Comparison of RNAV MDA With Other Approach Minimums (continued)

Table 5.4 Difference in RNAV MDA or DH

		mean difference ($\bar{x}$)	standard deviation (S_x)
RNAV MDA higher	ILS	+141	140
RNAV MDA lower	ASR	-3	124
	VOR/DME	-20	87
	NDB	-56	130
	VOR	-88	213

The primary reason for improvement in approach minimums through use of RNAV lies in the elimination of circling approaches. The resultant increase in safety is even more significant than the minor reduction in MDA, particularly for higher performance aircraft. A recent analysis [54] indicated that National Transportation Safety Board (NTSB) files showed a total of 42 accidents involving approaches in a three year period. These accidents exhibited the following characteristics:

- pilots - 24% Airline Transport Pilot, 40% commerical certificates
- aircraft - 6 turbojets, 1 turboprop, 25 piston twins, 10 single engine
- fatalities - resulted in 52% compared with 14% for all types of accidents
- type of approach - 76% VOR, 17% ILS, 5% back course ILS, 2% ADF

In addition to the elimination, or reduction, of circling approaches, RNAV offers the further advantage of positive orientation with respect to the landing runway. This feature can be used as a backup monitor for ILS, back course and ASR approaches.

3D RNAV also offers the potential for increased safety through more precise altitude control and orientation. Although 3D accuracies are such that no reduction in MDA can be expected (see Section 4.5), distinct advantages can be gained through its use. A non-precision approach is basically "unstabilized". The aircraft is configured for initial descent, reconfigured to maintain MDA, and reconfigured again for final descent. By using 3D RNAV for vertical guidance monitoring from final approach fix to the runway, the approach configuration can be stabilized and, in effect, MDA becomes decision height. Extreme care must be exercised, however, in establishing and entering 3D waypoints. Flight test and simulation results have indicated that due to increased requirements for data entry in some systems blunder potential is increased.

RNAV approach procedures also can provide for separation between V/STOL and conventional (CTOL) traffic. In some cases, separate non-conflicting approach paths to the touchdown point on STOL runways can be provided. This technique has been used by Airtransit Canada in their STOL demonstration project

coordinated by the Canadian Ministry of Transport [55]. Routes between Ottawa and Montreal were structured to achieve minimum block times, consistent with minimum conflict with CTOL traffic. RNAV procedures are utilized to maintain segregation from CTOL traffic and to intercept MLS type approach facilities while satisfying obstacle clearance limits, and noise abatement requirements.

RNAV procedures have also been utilized to develop conflict-free helicopter approaches to the downtown-Manhattan heliport. The "copter RNAV" procedure provides an approach to a "point in space" where transition to helicopter special VFR procedures is accomplished. An example approach plate is given in Figure 5.2.

A rather obvious but significant benefit available from RNAV approach procedures is the distance saved in transitioning from terminal area arrival fix to initial approach fix. The flexibility available with RNAV allows placement of the initial approach fix along the arrival path. An example is given in Figure 5.3 for arrival to Alameda County airport near Albuquerque, New Mexico. An aircraft arriving from the north can accomplish a straight-in RNAV approach to runway 17 with 34 miles less distance traveled than if a VORTAC circling approach is required. No attempt was made to estimate the total distance saved annually, but many airports can be expected to exhibit similar characteristics.

VFR noise abatement procedures exist at many airports which cannot be flown under IFR conditions. RNAV offers the potential for IFR noise abatement procedures at some airports similar to those commonly associated with eventual MLS implementation. As an example (taken from reference 56), consider the current visual approach procedure to runway 13 at New York's LaGuardia Airport. The procedure involves a flight path over the Hudson River to intercept the ILS course 5 nm from the runway threshold (Figure 5.4). The procedure serves to concentrate the noise over the River during the initial phase of the approach. Relative to the straight-in ILS approach to runway 13, the noise abatement potential for this visual approach is significant. Along the ILS approach the aircraft is below 2000 feet (and the noise perceived on the ground is significant) along the last 7 nm of the final approach. For the visual (noise abatement) approach nearly 30% of these last 7 miles would be flown over water, therefore reducing the degree of noise exposure in comparison to the straight-in ILS approach. The visual approach is very nearly optimum in terms of the noise abatement potential on runway 18. Even with the broad coverage capability of MLS, any further reduction in the noise exposure would not be possible because of Harlem's proximity to the LaGuardia Airport.

The minima for this approach require a 3200 ft. ceiling and a visibility of 5 nm. If an RNAV approach duplicating the ground track of the visual procedure were established, then the minima could be reduced to those for the ILS approach (200 ft. and .5 nm) and the noise abatement procedure would thus apply under conditions when instrument flight rules prevail. An appropriate RNAV approach procedure, shown in Figure 5.5, involves 3 waypoints directing the flight path of arriving aircraft over the Hudson River to the interception of the ILS localizer and glideslope approximately 5 nm from the runway threshold. The broken lines either side of the nominal flight path

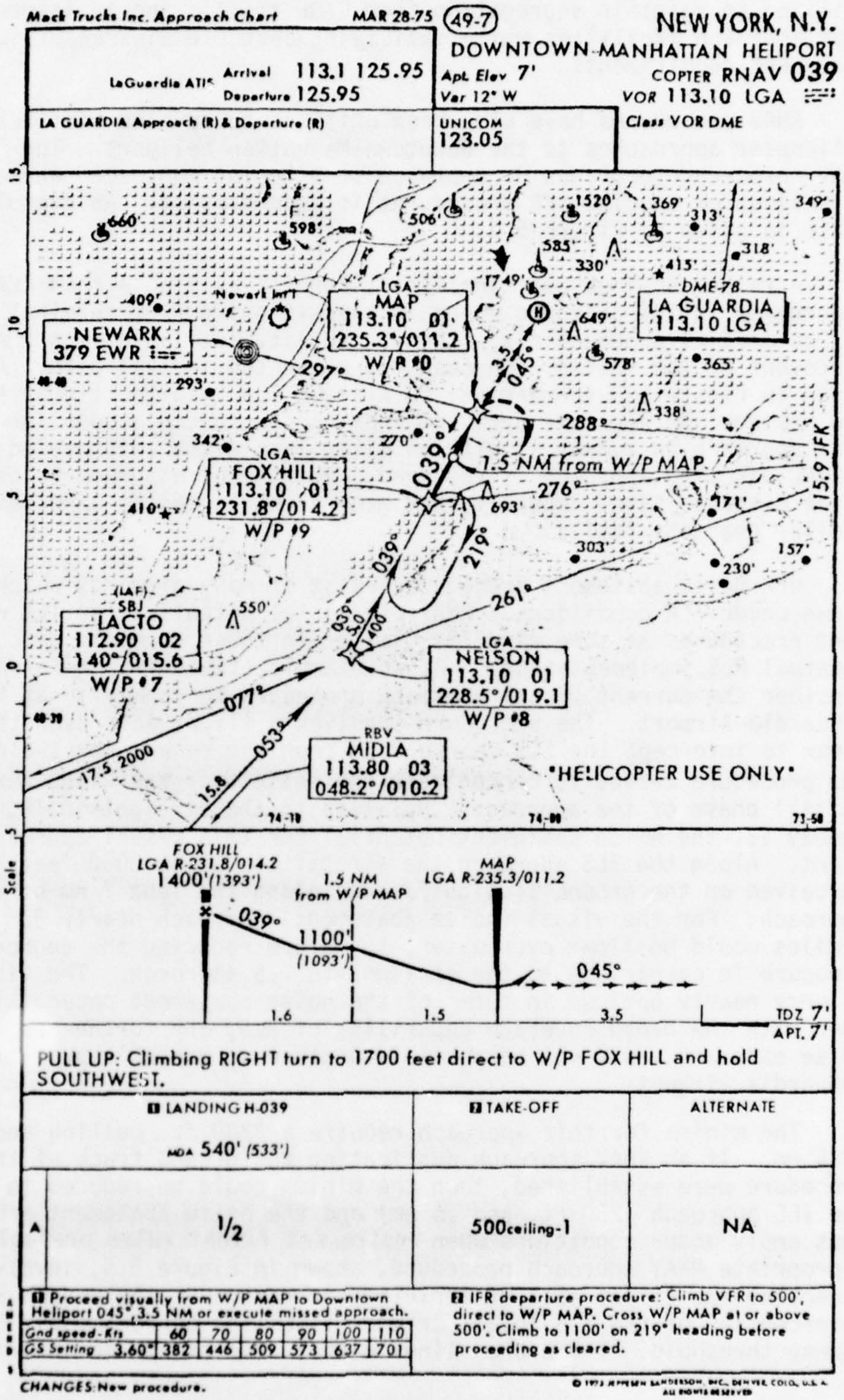
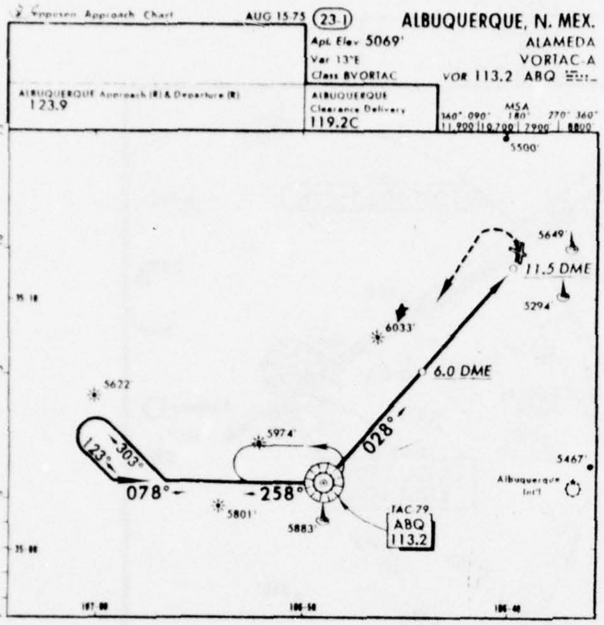
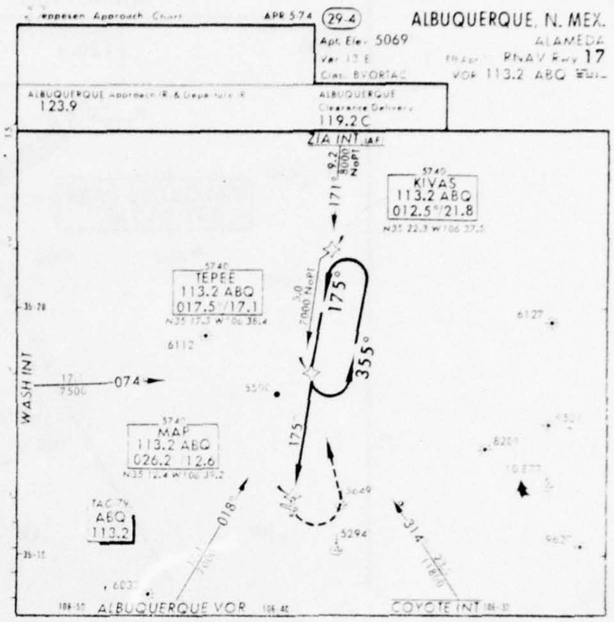
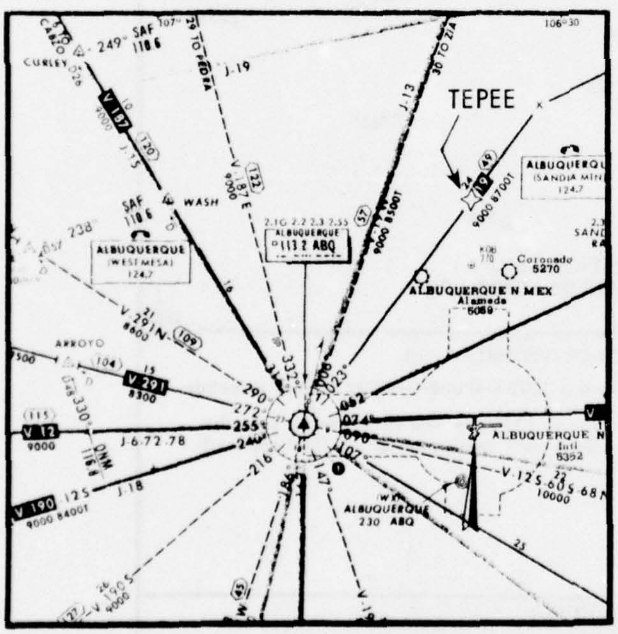


Figure 5.2

Copter RNAV Approach







VORTAC - A (FROM NORTH) (RWY 17)	
ZIA - ABQ	30.0 nm
Procedure turn	8.0
ABQ - AIRPORT	11.5
CIRCLE TO LAND	2.0
TOTAL DISTANCE	53.5 nm
RNAV (FROM NORTH) (RWY 17)	
ZIA - TEPEE	14.2 nm
TEPEE - AIRPORT	5.0
TOTAL DISTANCE	19.2 nm
DISTANCE SAVED	34.3 nm

Figure 5.3

RNAV Approach Distance Savings

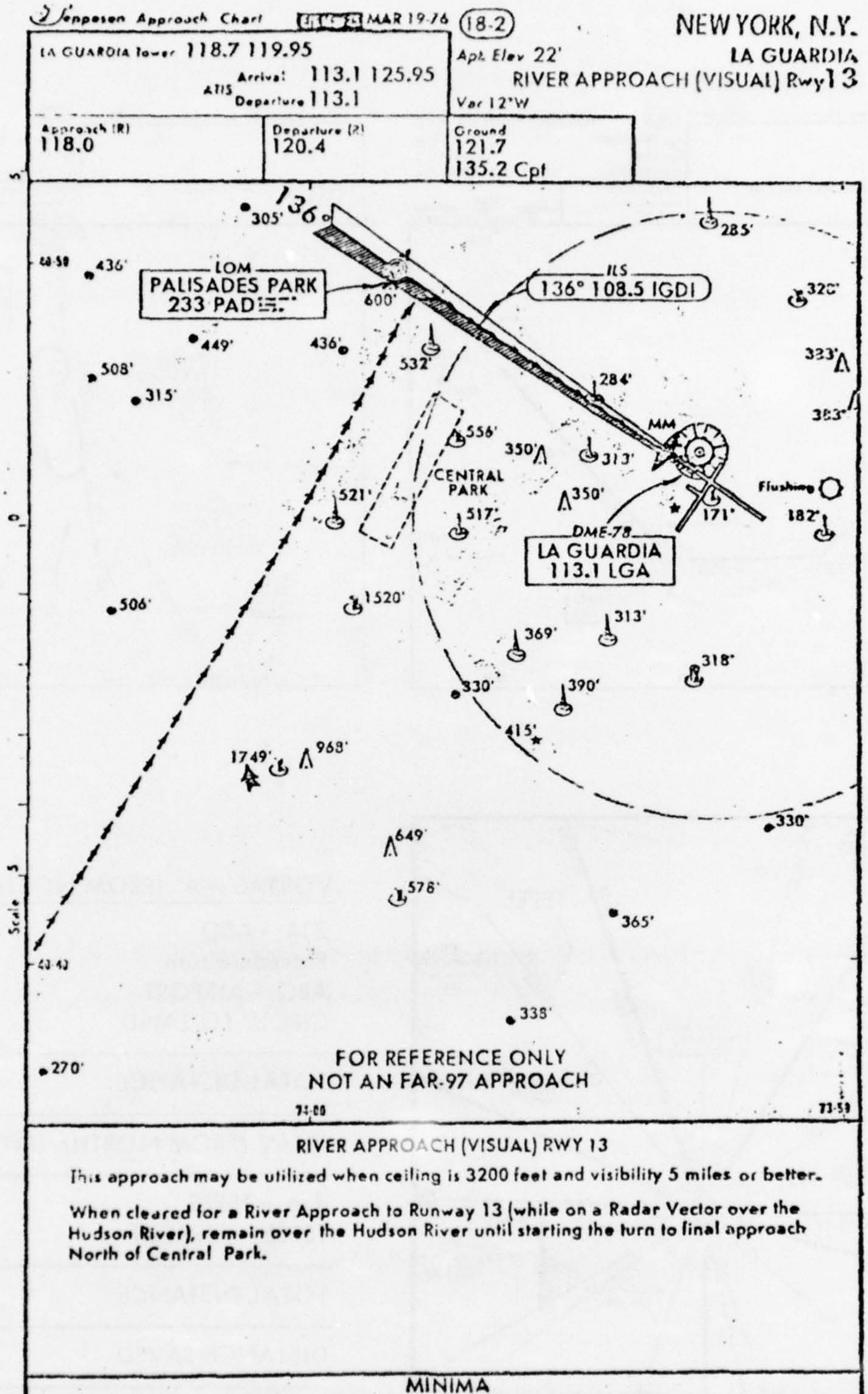


Figure 5.4 Hudson River Visual Approach to LGA-Runway 13

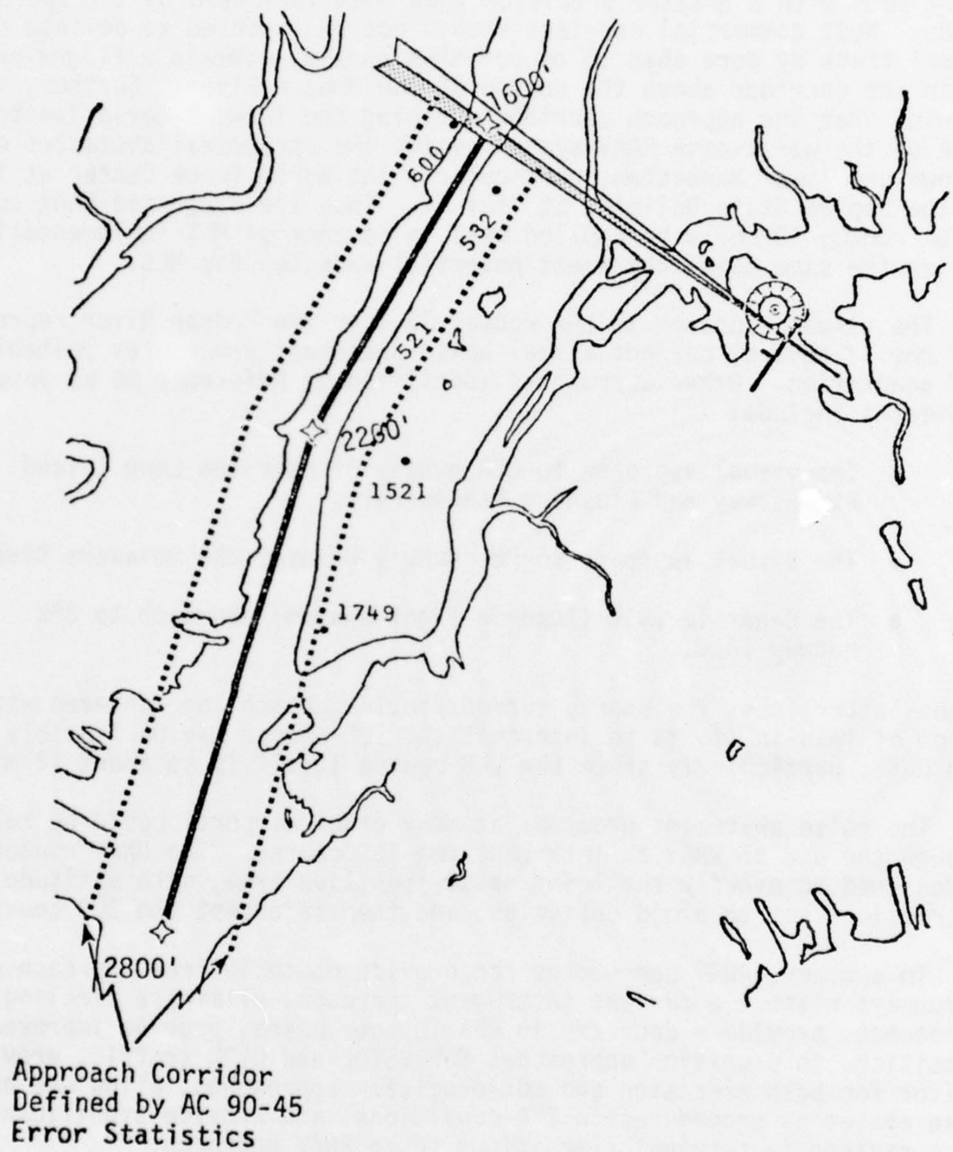


Figure 5.5 RNAV IFR Noise Abatement to LGA Runway 13

indicate the approach corridor defined by the maximum error statistics of AC 90-45A. Again it should be emphasized that the AC 90-45A statistics represent an upper bound on the errors permitted for an acceptable RNAV system. Thus it is expected that most aircraft will maintain the nominal flight path with a greater precision than that indicated by the approach corridor bounds. Most commercial carriers should not be expected to deviate from the nominal track by more than .3 nm and thus should maintain a flight path within the corridor above the course of the Hudson River. Further, it should be noted that the approach corridor defining the lateral deviation from track of the worst-case RNAV system avoids the structural obstacles of midtown and lower Manhattan, particularly the World Trade Center at 1749 ft. and the Empire State Building at 1521 ft. Thus the suggested RNAV approach to LGA runway 13 could be applied well in advance of MLS implementation to realize the same noise abatement potential expected for MLS.

The visual approach to LGA runway 13 over the Hudson River represents only one of several current visual noise abatement procedures suitable for RNAV adaptation. Other approaches identified by Reference 56 as potential candidates include:

- The visual approach to LGA runway 31 over the Long Island Expressway and Flushing Meadow Park.

- The Visual approach to PHL runway 9R over the Delaware River

- The Canarsie LDIN (lead-in light system) approach to JFK runway 13L.

In the latter case, the short, curved final approach leg achieved with the system of lead-in lights to intercept the ILS course may be feasible with RNAV, particularly since the ILS course itself is so short (2 miles).

The noise abatement problems at many other airports could be relieved through the use of RNAV to intercept the ILS course. The RNAV routes would be designed to overfly the least noise-sensitive area, with altitude restrictions set to avoid obstacles, and then intercept the ILS course.

In summary, RNAV approaches can provide obstacle-free approach paths to runways without a current instrument approach, eliminate circling approaches, provide a decrease in MDA in some cases, provide improved transitions to precision approaches for VSTOL and CTOL traffic, provide a monitor for both precision and non-precision approaches, allow use of noise abatement procedures in IFR conditions, and provide significant distance savings in terminal transitions to an RNAV approach.

5.1.2 Enroute Benefits

5.1.2.1 Route Length Effects

The analysis reported in Reference 12 was based on preliminary results of the NAFEC high altitude route structure analysis [4] and included flight mile fuel and time differences between charted RNAV, direct, and charted VOR

traffic due to route length differences and due to differences in number and types of conflicts and conflict resolution techniques. Subsequent efforts included the design and analysis of a 429 airport pair structure, expanded from the 185 airport pair structure upon which the preliminary analysis was based, and including consideration of weather routes and restricted areas in the high altitude enroute structure. The high altitude route analysis is described in Section 3.2 and results of the updated conflict analysis are discussed in Section 5.1.2.2.

Table 5.5 *Average RNAV Route Length Savings over VOR in High Altitude Enroute Structure*

	No. of airport pairs in structure			
	185	429		
		no wind	including weather routes	including restricted areas
Average VOR flight length (nm)	590.68	475.89		
Average RNAV flight length (nm)	500.65	464.71		
Average Direct flight length(nm)	494.08	463.09		
RNAV structure advantage over VOR	1.77%	2.35%	1.79%	1.61%
Direct structure advantage over VOR	3.06%	2.69%	2.13%	1.95%

Table 5.5 gives the results of the flight mile analysis of the 429 airport pair high altitude route structure compared with the 185 airport pair-structures used in the previous analysis. Each route length was multiplied by the twenty-four hour traffic demand on that route as defined in the 1969 Peak Day sample. The sum of these flights was then, in each case, divided by the sum of the traffic demand between the selected airport pairs to yield the average expected route length to be flown by an aircraft at random. The calibration of the no-wind analysis to include weather routes and restricted areas is described in Section 3.2. Calibration of the direct structure benefits was accomplished in the same manner, yielding the savings indicated in Table 5.5. The traffic demand on the 429 airport pair structure represented about 67% of total traffic, compared with about 41% of the total on the 185 airport pair structure. The 429 airport pair structure represents a fairly accurate model of a total structure, however, since it will accommodate approximately 92% of the total traffic with minor extensions to include traffic from airports in close proximity to routes on the structure.

Similar results were obtained in the low altitude route length analysis described in Section 3.3 and summarized in Table 5.6. The direct structure benefit in Table 5.6 was derived by a comparison of VOR and great circle flight miles in Table 3.21.

Table 5.6 Average RNAV Route Length Savings over VOR in Low Altitude Enroute Structure

Average VOR flight length (nm)	160.76
Average RNAV flight length (nm)	156.96
Average Direct flight length (nm)	154.96
RNAV structure advantage over VOR	2.36%
Direct structure advantage over VOR	4.17%

The benefits shown in Tables 5.5 and 5.6 are applicable to an average route length to be flown by an aircraft at random in a fully developed RNAV route structure, and the high altitude results are somewhat conservative since the NAFEC structure used as a basis for the analysis is not an optimum structure. However, they are also representative of the route length savings available on typical RNAV routes as they are implemented. The direct structure savings are also available now, depending upon controller workload and radar monitoring. Wide application of preplanned direct flights will be dependent upon implementation of improvements in the enroute automation systems and on extensive flight checking for area NAVAID coverage.

The estimated savings in fuel and time which will result from shorter RNAV route lengths may be computed as follows:

$$S = a \cdot \Delta l \cdot n \qquad (5.1)$$

where, S = annual savings in lbs or minutes in 1984

a = aircraft mix weighted average fuel in lb per mile or time in minutes per mile

Δl = average miles saved per departure = % saved x weighted average stage length less 110 miles (terminal area distance [12])

n = number of departures in 1984

The fleet mix of air carrier jet aircraft in 1984 was estimated from data provided by the Office of Aviation Policy of the FAA, as indicated in Table 5.7. The aircraft type weighted average values for "a" and for stage lengths in Equation (5.1) for air carrier aircraft were then derived from data in the Aircraft Cost and Performance Report [37] for CY1973. For air carrier aircraft, a = 25.2 lb/mile and 0.14 minutes/mile, and average stage length = 602 miles. Estimated total number of air carrier departures in 1984 is 6.3 million [21].

Table 5.7 Estimated Fleet Mix of Air Carrier Jet Aircraft in 1984

Aircraft Type	% of Total
4 engine wide body	5%
3 engine wide body	16%
4 engine regular body	4%
3 engine regular body	39%
2 engine regular body	36%

The 1972 mix of the business aircraft fleet was provided by the NBAA, as discussed in Section 5.1.1.1, and it was assumed that the 1984 mix would remain the same. Average fuel consumption was also obtained from NBAA data, and when combined with assumed average speeds of 450 mph for jets, 225 mph for turboprops and 120 mph for piston aircraft, resulted in estimates for "a" in equation (5.1) of 4.9 lb/mile and 0.13 minutes/mile for business jets, 3.3 lb/mile and 0.27 minutes/mile for business turboprops. Average stage lengths were also estimated from NBAA data as 514 miles for jets and 323 miles for turboprops. For all piston aircraft, "a" was estimated to be 0.8 lb/mile and 0.5 minutes per mile, with an average stage length of 226 miles. Total general aviation departures in 1984 were estimated from data in Reference 54 to be 6.5 million, of which 4.85% are business jet and turboprops, 14.75% are business piston aircraft, and 80.4% are other general aviation aircraft. Total estimated enroute fuel and time savings are summarized in Table 5.8. All air carrier and business jets and turboprops were assumed to fly in the high altitude structure and realize savings of 1.61% for charted RNAV and 1.95% for direct. The results are therefore conservative, since the portion of those flights which actually occur in the low altitude structure would save a larger percentage of route length. All piston aircraft were assumed to operate in the low altitude structure and realize savings of 2.36% for charted RNAV and 4.17% for preplanned direct.

Table 5.8 Total Fuel and Time Savings Over VOR in High and Low Altitude Enroute Structures in 1984

	Charted RNAV		Preplanned Direct	
	fuel (1000 lb)	time (1000 min)	fuel (1000 lb)	time (1000 min)
Air Carrier	1,097,320	6,108	1,329,000	7,415
business jets & turboprops	9,008	420	10,907	510
business piston	3,686	2,337	6,588	4,118
Total business aircraft	12,694	2,757	17,495	4,628
Other general aviation aircraft	22,300	13,900	39,400	24,600
TOTAL	1,132,314	22,765	1,385,895	36,643

5.1.2.2 Conflict Effects

The 185 and 429 airport pair charted high altitude RNAV route structures were subjected to fast time simulation to determine the effect of RNAV on system capacity and to generate data which could be used in a subsequent analysis to estimate the fuel and time impact of RNAV structure conflicts vs.

VOR structure conflicts, and to determine the impact on controller communications workload of various levels of VOR/RNAV traffic mixes. An analysis of the impact of conflicts on user fuel and time was performed utilizing the data from the initial fast time simulations of the 185 airport pair structure [12]. All conflicts which occurred during the simulation were solved in a post-simulation analysis through application of a conflict resolution logic model and the aggregate fuel and time used the resolution of the conflicts in a 100% RNAV traffic sample were compared with the aggregate fuel and time used in the resolution of the conflicts in a 100% VOR traffic sample. The results, when extrapolated to a national scale, indicated that a fuel benefit of 0.05% could be expected with 100% RNAV traffic compared with VOR. The difference in the time estimates was negligible. Since the conflict effects were an order of magnitude smaller than route length effects, they were not included in the computation of total annual benefits in both Reference 12 and this report.

5.1.2.3 Altitude Assignments.

The fuel savings due to conflict resolution differences included the impact of altitude restrictions during climb. Significantly fewer altitude restrictions were used in solving RNAV conflicts, primarily due to the convenience of the parallel offset maneuver. The availability of parallel routes, with little effect on conflict penalties, will both increase capacity and provide for more optimum altitude assignments in addition to the reduction in altitude restrictions during climbs. A rigorous analysis of the expected improvement in the distribution of altitude assignments in an RNAV environment is beyond the scope of this study. However, some insight may be gained into the magnitude of savings available by examination of several individual aircraft performance characteristics. Table 5.9 lists typical altitude related fuel penalties for several aircraft.

Table 5.9 Altitude Restriction Fuel Penalties

A/C Type	DC-8-63	DC-9-30	B-727	B-747
Flight Level For Zero Penalty	350	350	350	350
Mach No.	.80	.77	.80	.84
Gross Weight (x1000 lb.)	260	90	140	600
Flight Level	Penalty - Pounds of Fuel per Minute			
100	116	58	90	183
130	104	49	85	171
150	93	33	79	159
200	74	27	51	140
250	39	25	26	83
270	28	17	20	50
290	17	12	13	18
310	9	7	5	0
330	3	0	0	0

It can be seen that a difference of one Eastbound or Westbound flight level can have a significant effect on fuel consumption (wind and other factors being constant).

5.1.3 Annual User Benefits

The fuel and time savings, comparing RNAV over VOR, for both terminal area and enroute operation were summarized in Sections 5.1.1 and 5.1.2 for three classes of users: air carrier, business and other general aviation operators. In this section estimates are made of the dollar value of those annual fuel and time savings.

5.1.3.1 Air Carrier Annual Benefits

Utilizing data from the Aircraft Cost and Performance Report [37] and the aircraft fleet mix derived in Section 5.1.2, the average cost of a minute of delay was estimated. The cost of fuel, oil, depreciation, and rentals was subtracted from total operating cost to obtain a flight-time sensitive (less fuel) cost of delay. The fleet mix weighted average was $8.40 per minute for CY1973. This cost was then inflated by 14.5% to arrive at an estimate of $9.62 per minute for average delay cost, less fuel, in 1975 dollars. The average 1975 airline jet fuel cost was estimated by inflating average fuel cost reported in the last quarter 1974 operating cost data for the 747, DC-10 and L1011 [57] by 10%. Fuel cost in 1975 was therefore conservatively estimated at $.23 per gallon, or $.036 per pound. These costs were applied to the terminal area 2D and 3D, and the enroute fuel and time savings. The air carrier estimates of cost of delay which were used in the 4D analysis of Section 3.4 were based on 1973 dollars, and included a mix of ground and airborne ATC induced delay. The fuel savings through 4D in M & S terminals were estimated in Section 5.1.1. Using an average 1973 fuel cost of $.13 per gallon [57], the time portion of the total savings of $9.46 per minute was estimated to be $7.25 in 1973 dollars, or $8.30 in 1975 dollars.

Total annual air carrier savings are summarized in Table 5.10 for 1984 traffic levels in 1975 dollars. The passenger time savings given in Table 5.10 are based on average number of revenue passengers for each aircraft type [58] and an assumed value of passenger time of $12.50 per hour [59].

Table 5.10 **Annual Air Carrier Jet Aircraft Savings RNAV over VOR at 1984 Traffic Levels (1975 dollars)**

	Annual Savings in Millions of Dollars				
	Aircraft Fuel	Aircraft Time	Sub-Total	Passenger Time	Total
Terminal Area - 2D	35.9	55.2	91.1	93.5	184.6
Terminal Area-3D descent	17.2	31.9	49.1	45.8	94.9
4D in M&S Terminal	35.3	75.1	110.4	142.1	252.5
enroute	39.5	58.8	98.3	95.9	194.2
Total	127.9	221.0	348.9	377.3	726.2

The terminal area savings are larger than those estimated in the previous study [12] due to an improvement in the terminal area designs [2], coupled with the fact that the current estimate is based on 60 major airports compared with only 8 airports (6 terminal areas) in the previous study. The enroute savings are also much larger than those estimated in Reference 12 due to the following factors: 1) average total cost per mile increased from $1.59 to $2.23 (40%); 2) average enroute route length increased from 407 to 492 nm (21%); 3) average number of high altitude departures only for 1982, (3.6 million) were used in Reference 12, where total high and low altitude savings were estimated in this study (6.3 million air carrier departures in 1984), resulting in a further increase of 75%.

5.1.3.2 Business Aircraft Annual Benefits

The cost of jet fuel and aviation gasoline for business (and general aviation) operators was estimated from information obtained from a telephone survey of Fixed Base Operators in July, 1975. The estimated 1975 cost is $.70 per gal. for jet fuel and $.72 per gallon for aviation gasoline, or approximately $.12 per pound for each. The cost of delay was conservatively estimated to consist only of maintenance cost. The average maintenance cost was derived from operating cost data provided by the NBAA. The average delay cost (less fuel) for all jet, turboprop, and piston business aircraft was estimated to be $.15 per minute in 1975 dollars. Table 5.11 summarizes annual savings to business aircraft operators in 1984 through RNAV compared with VOR. Savings due to pilot-selected 3D descents in the terminal area can be substantial for individual jet aircraft but the total savings were not estimated, since less than 5% of business aircraft are jets. The passenger time savings given in Table 5.11 are based on average passenger loads for various business aircraft from NBAA data, and on an assumed value of passenger time of $12.50 per hour [59]. Although some companies utilize a "value added" concept to compute values of executive time which can range as high as $40 per minute, no attempt was made to quantify these additional passenger time benefits.

Table 5.11 Annual Business Aircraft Savings RNAV over VOR at 1984 Traffic Levels (1975 dollars)

	Annual Savings in Millions of Dollars				
	Aircraft Fuel	Aircraft Time	Sub-Total	Pass. Time	Total
Terminal Area - 2D	.46	.17	.63	.87	1.50
Enroute	1.52	.42	1.94	2.17	4.11
Total	1.98	.59	2.57	3.04	5.61

5.1.3.3 Other General Aviation Annual Benefits

Average overhaul costs for general aviation aircraft were estimated from a 1972 Aircraft Price Digest [60], updated by a telephone survey of Fixed Base Operators. The estimates ranged from $.14 minute of flight time for light twins to $.02 per minute for single engine, four place aircraft. The fleet weighted average overhaul cost for general aviation aircraft in 1975 dollars was estimated to be $.03 per minute. Routine maintenance and calendar inspections were not included. The fuel cost was estimated at $.12 per pound as in the case of business aircraft.

A summary of annual savings for non-business general aviation aircraft is given in Table 5.12. A passenger time value was not considered appropriate for pleasure flying and was not computed.

Table 5.12 Annual Non-Business General Aviation Aircraft Savings RNAV over VOR at 1984 Traffic Levels (1975 dollars)

	Annual Savings in Millions of Dollars		
	Fuel	Time	Total
Terminal Area - 2D	1.07	.17	1.24
Enroute	2.68	.42	3.10
Total	3.75	.59	4.34

5.1.3.4 Total Annual User Benefits

Table 5.13 summarizes total annual user benefits for air carrier, business, and other general aviation aircraft.

Table 5.13 Total Annual User Savings RNAV over VOR at 1984 Traffic Levels (1975 dollars)

	Annual Savings in Millions of Dollars				
	Aircraft Fuel	Aircraft Time	Sub-Total	Pass. Time	Total
Air Carrier	127.9	221.0	348.9	377.3	726.2
Business	2.0	0.6	2.6	3.0	5.6
Other Gen.Aviation	3.7	0.6	4.3	——	4.3
Total	133.6	222.2	355.8	380.3	736.1

The savings summarized in Table 5.13 are predicated on a charted RNAV structure enroute. Although the savings available in a preplanned direct enroute environment are 21% greater than in a charted RNAV structure, the total RNAV savings in 1984, including terminal and enroute, are only 6% greater for the total RNAV environment which utilizes all preplanned direct in lieu of charted RNAV enroute.

5.1.4 User Equipment Impact

The levels of RNAV capability and the airborne equipment costs necessary to obtain each level were analyzed in Section 3.5. Systems which meet the minimum operational characteristics [7] will range in price from $3000 to $100,000. However, the 2D RNAV savings desribed in Section 5.1.3 are available to any aircraft equipped with the most basic system. This section discusses the cost of equipping compared with the benefits to be realized for each user group.

5.1.4.1 Air Carrier Equipment Impact

The savings available over VOR to the estimated 3100 U.S. air carrier jet aircraft in 1984 are $203 million per year for 2D RNAV (terminal plus enroute) and an additional savings of $49 million per year for 3D descents and $110 million for 4D in M & S terminals. The 2D savings alone will support an average amortization of airborne equipment cost of $65,000 per year per aircraft. Addition of 3D and 4D capability, which are relatively small increments of the basic cost of an airline quality RNAV system, will increase the available payback per year per aircraft by $16,000 for 3D and by $36,000 for 4D.

5.1.4.2 Business Aircraft Equipment Impact

The total annual business aircraft savings of $2.57 million derived in Section 5.1.3.2 is the maximum possible savings, based on all aircraft being equipped with RNAV. If only those aircraft are equipped which would be required to have RNAV, for operation in the high altitude structure and at high and medium density hub airports (see Section 3.5), then only 11,000 of the projected 67,000 business aircraft in 1984 will accrue benefits, and the total savings will be reduced proportionately. The total cost to equip these 11,000 aircraft with RNAV is $66.4 million, or an average of $6000 per aircraft. Based on the data presented in Table 5.10, an average business aircraft can expect to save approximately 3% of annual operating cost (fuel and maintenance) with RNAV. (This estimate was derived by inflating the 1.61% and 2.36% enroute distance savings to include terminal area savings.) Since annual dollar savings are dependent upon annual operating cost and independent of RNAV equipment cost, payback will be much faster for higher performance aircraft. Estimated annual savings for an average business aircraft in each of four categories is given below:

Type Aircraft	Estimated annual savings due to 2D RNAV (fuel and maintenance only)
jet	$5850
turboprop	2070
piston multi-engine	297
piston single-engine	40

It can be seen that a reasonable payback period can be projected on the basis of fuel and maintenance cost savings alone for jets and turboprops. However, the value of passenger time must be considered to obtain a reasonable payback period for piston aircraft. Piston business aircraft flew an average of 257 hours in 1973 according to NBAA data. Projected additional savings would average 8 aircraft hours at an average passenger load factor of 3+. Even conservative estimates of the value of executive time would result in substantial additional savings and provide a reasonable payback for the cost of RNAV equipment.

5.1.4.3 Non-Business General Aviation Equipment Impact

As in the case of business aircraft, the total annual general aviation savings of $4.46 million per year represent the maximum available if all aircraft were RNAV equipped. With the TCA concept described in Section 3.5, only 7,500 of the estimated 145,000 non-business general aviation aircraft in 1984 would be required to have RNAV. The cost to equip these 7,500 aircraft is $37.3 million, or an average of $5,000 per aircraft. It should be noted that more than 4000 of these aircraft do not have DME, and that the DME cost is included in the average.

As was discussed in Section 5.1.4.2, a reasonable payback period for RNAV equipment for small piston aircraft cannot be projected on savings in fuel and maintenance cost alone. However, as evidenced by the current popularity of RNAV equipment among general aviation users (over 4500 equipped), there are other benefits available which are difficult to quantify. Among these benefits are its use as a VFR pilotage aid, elimination of circling approaches, and access to airports which do not currently have a VOR approach. The tendency of general aviation operators to purchase navigation equipment to obtain additional capability even when not required is evidenced by the fact that more than 25,000 general aviation aircraft are equipped with DME. It is therefore reasonable to anticipate that many more than the 5% of non-business general aviation aircraft which would be required to have RNAV under the TCA concept would actually equip.

5.1.4.4 Impact on Military Aircraft

The Department of Defense operates more than 27,000 aircraft, making them one of the largest of the users of the National Airspace System. In the DOD comments on the Task Force Report [61], it was pointed out that any program to implement RNAV on a mandatory basis must consider the extensive

effort and expenditures required to equip military aircraft. A very limited number of military aircraft have a navigation capability that would be directly usable for the area navigation concept recommended by the Task Force, and a minimum of seven years lead time would be required, after approval of the RNAV concept, to include the necessary funds in the Federal Budget, to procure equipment, and to complete all aircraft modifications.

The impact of RNAV implementation on military operations and equipment requirements will be largely dependent upon the implementation concept and timing. The questions which military planners must answer include the following:

1) How many aircraft (and what type) have a requirement to fly in the national airspace system?

   a) High altitude structure (FL180-FL450)
   b) Low altitude structure
   c) High density terminal areas
   d) Medium density terminal areas

2) What is current and planned navigation capability of each type?

3) Which aircraft would be required to have RNAV capability? When?

4) What aircraft could attain RNAV capability through modification of existing or planned navigation equipment?

   a) Software modification only
   b) Minor mechanical modification
   c) Major modification

5) What are flight test requirements?

   a) for certification to current standards (AC90-45A)
   b) for certification of other than VOR/DME or TACAN based navigation equipment

6) What equipment or procedural requirements are assumed which, if relaxed, would have a major impact on either 4) or 5) above? What relaxation of requirements would be necessary?

7) What are overall retrofit requirements?

   a) Schedule
   b) Training and support requirements
   c) Funding requirements

8) What benefits to military operations could be realized through the use of RNAV?

The potential impact on military operations and equipment requirements caused by the implementation of RNAV varies widely among the services. In the following paragraphs, a brief assessment is made of current navigation capability of each military service, plus the U.S. Coast Guard, as it applies to Area Navigation.

The Air Force flies more than eighty aircraft types, of which approximately twenty types are equipped with inertial systems and twenty types are equipped with doppler navigation systems. With the exception of the VIP fleet and the Military Airlift Command transport aircraft, very few of these systems have either the necessary long range accuracy or the capability for VORTAC update to accommodate RNAV operations. The majority of Air Force tactical aircraft are equipped with both VOR and Tacan. However, they are extremely space limited and would require retrofit with newly developed dual-purpose equipment to accommodate both primary mission requirements and navigation capability in an RNAV environment. Table 5.14 presents a summary of Air Force aircraft navigation capability.

In many ways, Army aviation operations in the National Airspace System are similar to those of general aviation. Aircraft types range from light utility helicopters to medium size turboprops. The aircraft are broadly dispersed geographically, and flights range from a variety of tactical missions to VFR and IFR operation in the low altitude structure. Only four percent of the approximately 10,000 Army aircraft even fly in the high altitude structure (OV-1, UX and a few U-21s). It is estimated, based on conversations with Army personnel, that a like percentage (3-5%) of the total inventory will ever operate in Group I and Group II TCAs. A listing of Army aircraft and current and planned navigation capability is given in Table 5.15.

Of the estimated 375 aircraft which would be required to have RNAV capability because of operation in the high altitude structure (OV-1 and UX), the 225 OV-1 aircraft have dead reckoning navigation systems which could be adapted for RNAV use. The 120 UX aircraft are equipped with a Tacan, and therefore would need only an RNAV computer. If the other aircraft were required to have RNAV capability, primarily due to operation in high and medium density terminals, an additional 1500, plus the UTTAS and AAH, could possibly utilize Loran as an RNAV system. Of the remaining aircraft, only the U-8 and U-21 (361 aircraft) will have VOR/DME or Tacan and therefore require only an RNAV computer. The remaining 8000 aircraft would require a DME as well, and 2000 of those would also require VOR (or Tacan).

Fifty percent of the approximately 7000 Navy aircraft are equipped with Tacan which is suitable for conversion to RNAV capability and all of the long range Navy aircraft are equipped, or will be equipped with Loran-C. The P3B, P3C, A7D, A7E, S3 and F14 fleets are equipped with inertial navigation systems which are adaptable to RNAV operation. The remaining aircraft could not be equipped for RNAV operation without a massive equipment development and retrofit program. Aircraft such as the A4, F4 and A6 are extremely space limited and RNAV capability could not be provided through addition of separate RNAV equipment.

Table 5.14 USAF Aircraft Navigation Equipment

Aircraft	Tacan	VOR	DME	Loran C/D	Omega	Inertial Type	Inertial Accuracy (nm/hr.)	Doppler
A-7D	x					ASN-90	.74	APN-190
A-10	x	x						
A-37	x	x						
A-1E	x	x						
B-1	x					ASN-101	.10	APN-185
B -52B	x	x						
B-52C	x	x						APN-89
B-52D/E/F	x	x						APN-108
B-52G/H	x	x				LN-15A	.50	APN-89A
FB-111	x					AJN-16	.50	APN-185
B-57	x	x						
C-5A	x	x		x		NIS-105	.80	Nortronics
C-7A	x	x						
C-9A	x	x	x					
C-47	x							
KC-97	x	x						
VC/C-118A	x	x						
C-119	x	x						
C-123	x	x						
C-124	x	x						APN-147
C-130	x	x		some	planned			APN-147
C-131	x	x						
C-135	x	x				planned	<1.0	
C-140	x	x						NC-103
VC-137	x			x		LTN-51	1.0	
C-141						planned	<1.0	APN-147
EC-135	x							APN-81
EC-137	x							
EC-121	x	x		some				APN-153
EB-66	x	x						APN-82
F-4	x	x		planned		LN-12	3.0	
F-5E	x					LN-33	1.0	
F-15	x					LN-31		
F-100/101/102/106	x							
F-105	x			some		ASN-100		
F-111A/E	x					LN-14	2.0	
F-111D/F						LN-16	0.5	
F-104	x					LN-12	3.0	
RF-4C						x		
RF-101	x							
RF-5A	x							
T-29	x	x						
T-33	x	x						
T-37		x	x					
T-38	x							
T-39	x							
T-41		x						
T-43		x						
U-3		x						
U-4		x						
U-6		x						
U-10		x						
U-17		x						
H-3	x	x						APN-175
H-53		x						APN-175
H-1	x	x						
O-2	x	x						
OV-10	x	x						

Table 5.15 Army Aircraft Navigation Capability

Type	Current					Planned
	Tacan	VOR	Doppler	INS	Loran	
OV-1	X	X	X	X		
T-41		X				
T-42		X				
U-1		X				
U-6		X				
U-8		X				+ DME
U-10		X				
U-21	X	X				
AH-1						+ Doppler
CH-34		X				
CH-47		X				+ Loran
CH-54		X				
OH-6						+ VOR (50%)
OH-13						
OH-23						
OH-58						+ VOR (50%)
TH-13		X				
TH-55						
UH-1		X				+ Loran (10%)
UTTAS		X			X	
AAH					X	
UX	X	X				

The impact on the Coast Guard would be nominal since all USCG aircraft have relatively sophisticated multi-sensor navigation systems designed for logistics and search and rescue missions.

The current and planned Coast Guard aircraft fleet and navigation capability is listed in Table 5.16.

Table 5.16 USCG Aircraft

Aircraft Type	VOR	DME	TACAN	INS	Loran A	Loran C	Nav. Comp.
HU-16E	X	X	X		X		
HH-52A	X		X				
HH-3F	X		X		X	X	AYN-1
HC-130B	X	X	X	ARINC-561	X	X	ARINC-161
HC-130H	X	X	X	ARINC-561	X		AYN-1
VC-4	X	X					
VC-11	X	X		ARINC-561			ARINC-561
MRS	X	X		X			Mk-2

The HU-16E (Grumman Albatross) fleet is in the process of being phased out and will not be affected by an RNAV requirement. The fleet of 94 HH-52A helicopters are equipped with the necessary sensors but would require the addition of RNAV equipment. The HH-3F helicopters are currently equipped with the AYN-1 navigation computer which can be adapted for RNAV use through development of appropriate procedures. The HC-130 B/H aircraft are equipped with ARINC-561 inertial systems which can be adapted for DME update. The single VC-4 (Gulfstream I) will require the addition of RNAV equipment, and the VC-11 (Gulfstream II) is equipped with ARINC-561 inertial. The new Medium Range Search aircraft (MRS) fleet will be equipped with ARINC-582 area navigation equipment. It is anticipated that the use of RNAV procedures will allow establishment of discrete tactical arrival and departure routes in busy terminal areas which will enhance the quick response of search and rescue missions with procedural separation from other traffic.

Many tactical aircraft are only occasional users of the National Airspace System and therefore would accrue the benefits of RNAV at a slower rate than the constant users. However, the military constitutes in total a very large segment of the users of the National Airspace System, and are in general the only users whose primary mission requirement is not the ability to navigate within a specific airways structure. The preplanned direct operational concept described in Section 5.4, which allows the use of VORTACs as waypoints, could form the basis for a transitional implementation requirement for these military aircraft with a secondary mission requirement to navigate in the NAS, with an ultimate requirement that all military aircraft conform to the same equipment and procedural standards as other users of the NAS when user demand is sufficient to warrant proceding to the second and third implementation phases. The ability to navigate on a "VORTAC direct" basis during the transition period in both the high and low altitude RNAV structures would then allow military aircraft access to the National Airspace System with no reduction in operational flexibility under that currently available in the VOR airways structure. Normal operation could therefore continue during the seven year period which DOD has estimated as being required to obtain full RNAV capability. The Air Force, Navy and Coast Guard have a requirement for virtually all their aircraft to fly in the National Airspace System. The Army requirement is much less severe - probably less than 5% of their aircraft would be required to have RNAV equipment.

5.1.5 Transition Period User Benefits

The user benefits described in Sections 5.1.1, 5.1.2, and 5.1.3 are applicable to an all-RNAV environment in 1984. The realization of benefits by individual users, however, is not dependent upon an all-RNAV environment. The implementation concept described in Section 5.4 is based on providing enroute and terminal RNAV routes on a gradual basis in accordance with user demand. An example of a potential RNAV implementation scenario is given in Table 5.17. If it is assumed that 2D and 4D terminal area benefits are available to equipped aircraft as RNAV is implemented in the terminal areas, that 3D and enroute benefits are available as aircraft are equipped with RNAV on a schedule which is planned to correspond with the availability of routes, the annual air carrier transition period savings, derived from an analysis described in Reference 14, are as indicated in Table 5.17.

AD-A039 225 SYSTEMS CONTROL INC PALO ALTO CALIF F/G 17/7
IMPLEMENTATION OF AREA NAVIGATION IN THE NATIONAL AIRSPACE SYST--ETC(U)
DEC 76 W H CLARK, E H BOLZ, H L SOLOMON DOT-FA72WA-3098
UNCLASSIFIED FAA-RD-76-196 NL

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A039225

Table 5.17 Transition Period Benefits

Table 5.17a Sample RNAV Implementation Scenario

Terminal Area RNAV Design Implementation by Calendar Year:

1982	1983	1984	1985	1986	1987	1988
EWR*	BOS*	TPA*	CVG*	BUF	ORF	BHM
LGA*	DFW*	CLE*	MEM	CLT	OKC	PVD
JFK*	DEN*	SEA*	PHX	IND	DAY	DSM
ORD*	FLL*	DTW*	SAN	SLC	OMA	ELP
LAX*	IAD	MSY*	MCO	MKE	JAX	RDU
ATL*	MIA*	IAH	BAL*	BDL	SAT	TYS
	SFO*	MCI	PDX	CMH	SDF	ALB
	DCA*	PHL*			ROC	TUL
		PIT*			SYR	SMF
		MSP*			ABQ	
		STL*			BNA	
		LAS*				

*4D M&S Implemented starting in 1985

Fleet mix and percent of aircraft equipped with RNAV

	1982		1983		1984		1985		1986		1987		1988	
	% of flt	% eqp	% of flt	% eqp	% of flt	% eqp	% of flt	% eqp	% of flt	% eqp	% of flt	% eqp	% of flt	% eqp
4Eng W.B.	4.1	33	4.3	67	4.6	100	4.8	100	5.2	100	5.6	100	6.1	100
3Eng W.B.	12.5	35	13.2	68	13.8	100	14.4	100	16.7	100	18.9	100	20.9	100
4 Eng.	10.3	0	9.4	22	8.6	44	7.8	66	7.1	73	6.4	80	5.7	86
3 Eng.	46.2	0	48.1	33	49.9	67	51.4	100	50.4	100	49.5	100	48.6	100
2 Eng.	26.8	0	24.9	30	23.1	61	21.6	91	20.6	93	19.6	95	18.7	96

2D and 4D Terminal Area benefits assumed to be available to equipped aircraft as RNAV is implemented in the terminal areas. 3D and enroute **benefits assumed to be available as aircraft are equipped.**

Table 5.17b

Annual Air Carrier Transition Period Savings
-in millions of 1976 dollars -

calendar year	aircraft fuel	aircraft time	sub-total	passenger time	total
1982	6.3	6.0	12.3	9.6	21.9
1983	27.4	40.8	68.2	65.8	134.0
1984	53.6	72.7	126.3	117.5	243.8
1985	105.6	185.7	291.3	300.6	591.9
1986	111.7	209.6	321.3	341.3	662.6
1987	117.6	219.5	337.1	359.8	696.9
1988	123.1	252.8	375.9	406.2	782.1

5.2 SYSTEM IMPACT SUMMARY

The results of several analyses concerning the potential impact of RNAV implementation on the ATC System are reported in Section 4 of this report. In this section, the results of these studies, combined with the results of other related studies, are summarized as they relate to certain key areas of ATC System impact: VORTAC requirements, controller productivity and training, ATC automation, charting and flight inspection, airspace capacity and route development. This section is intended to summarize the overall impact of RNAV on the ATC system in these areas and it is recognized that the specific requirements and impact may differ in individual areas and cases.

5.2.1 VORTAC Station Coverage Requirements

The analysis of VORTAC system implementation costs described in Section 4.2 and 4.3 was intended as a preliminary overall estimate of the VORTAC costs required to support RNAV in the high altitude structure and the savings available through reduction of the number of VORTACs required to support navigation in the high altitude enroute area and in the terminal areas. It was not intended to supplant the requirement for the detailed analysis which should be conducted based on the development of an optimum enroute structure for implementation which is coordinated with detailed terminal area designs for the appropriate high and medium density terminal areas. The analysis is conservative in that the costs were determined relative to the existing VORTAC system, and no estimates were made of additional VORTAC requirements to support an expanded enroute VOR airways system which would meet the same traffic demand. The analysis of terminal area requirements was based on the removal of existing VORTACs. The enroute analysis did not include consideration of the removal of high altitude VORTACs which provide completely redundant coverage. It can be expected that a number of high altitude VORTACs can be eliminated when a detailed analysis is made based on the optimum route structure which is to be implemented, resulting in an annual maintenance savings of approximately $48,500 for each station removed. Elimination of only 12 VORTACs would provide first year maintenance savings equal to the one time cost of providing high altitude charted RNAV coverage in the 1977 period, and would pay for full CONUS coverage for 1977 in less than four years.

The estimated implementation cost to provide VORTAC coverage for the high altitude enroute structure is given in Table 5.18 for the Task Force recommended route widths for both charted and preplanned direct RNAV. The implementation cost to provide DME/DME coverage is also given. Part of all of the cost in Table 5.18 can be expected to be offset by annual maintenance savings from removal of redundant high altitude VORTACs, which were not considered in this study.

It was determined that the support of RNAV in high and medium density terminal areas would require a minimum of 48 fewer VORTACs than a VOR structure, for an annual maintenance savings of $2.3 million. One-time cost savings in in the terminal area could also include modernization costs of the 48 removed VORTACs.

Table 5.18 VORTAC Implementation Impact

	COSTS	
	VOR/DME	DME/DME
High Altitude Charted RNAV, ±4 nm route width	$597,300	$5,244,000
High Altitude Pre-planned Direct RNAV, ±4 nm route width	$1,959,900	$5,799,000
High Altitude Pre-planned Direct RNAV, ±2.5 nm route width	$6,604,000	$5,799,000

	Annual Maintenance Savings	
	Number of VORTACs	Dollars
Enroute	not determined	not determined
Terminal Area	48	$2,328,000

Table 5.19 is taken from the National Aviation System Plan [51], and gives the enroute Navigation Aids F & E Program Plan for 1976-85. It can be seen that the VORTAC implementation costs estimated for the RNAV high altitude structure are nominal when compared with normal planned expenditures for improvement and expansion of the VOR system, which average in excess of $20 million per year.

5.2.2 Controller Impact

5.2.2.1 Controller Productivity

A major concern of the Task Force was the possibility that air traffic controllers might experience an unacceptable increase in workload during the transition period of mixed VOR/RNAV operations prior to the advent of a predominently RNAV environment. As reported in Reference 12, it was determined that controllers are capable of operating in this mixed environment with reduced workload and no reduction in system capacity, and that significant reductions in controller communications time can be expected as the percent of RNAV traffic increases. These conclusions were supported by analyses based on data from both real-time [9] and fast-time [10] simulations. Additional fast-time simulations utilizing a much larger and more representative RNAV structure indicate similar trends in conflict reduction which were the basis of the previous analyses. Another previous analysis [13] concluded that

Table 5.19 **Enroute Navigation Aids F & E Program Plan**

Program	PLAN (Amount in millions of dollars)														Total	
	1976		1977		1978		1979		1980		1976–80		1981–85		1976–85	
	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.	No.	Amt.
VORTAC System		5.6		14.8		26.3		24.9		24.9		96.5		95.2		191.7
TVOR/VORTAC/VOR-DME																
Establish	5	1.1	5	2.5	5	2.5	5	2.5	5	2.5	25	11.1	25	12.5	50	23.6
Relocate	4	1.2	5	2.0	3	1.0	3	1.0	3	1.0	18	6.2	20	8.0	38	14.2
Convert	1	.2		—		—		—		—	1	.2		—	1	.2
Improve		1.9		7.5		20.0		20.0		20.0		69.4		60.7		130.1
Add DME to VOR/TVOR	20	1.2	40	2.8	40	2.8	20	1.4	20	1.4	140	9.6	100	14.0	240	23.6
Low and Medium Frequency NAVAIDS		.1		2.3		.5		.5		.5		3.9		6.0		9.9
Improve		.1		2.3		.5		.5		.5		3.9		6.0		9.9
Total		5.7		17.1		26.8		25.4		25.4		100.4		101.2		201.6

overall controller productivity increases of 10% in the terminal and 14% enroute could be expected in an all-RNAV environment compared with an all VOR airways environment. The data that supported this analysis was based on simulations which pre-dated the Task Force Report. Analysis of a subsequent terminal area real time simulation [11] indicated that RNAV equipped arrivals experienced a significant reduction in holding delays along with an increase in operation rates, which tends to verify the correlation between reduced workload and increased productivity. Although other aspects of enroute controller productivity were not further analyzed, the 30% increase in communications productivity both enroute and in the terminal area as reported in References 11 and 12 which were based on post-Task Force simulations, tend to support the earlier conclusions. In the terminal area, a substantial reduction in the use of radar vectors was also observed and navigation was returned to the cockpit through use of parallel offsets and direct to waypoint instructions.

5.2.2.2 Controller Training

One of the conclusions drawn from the real-time simulation of the New York terminal area [9] was that a thorough and extensive training program is necessary before controllers can use RNAV procedures in a way that will result in maximum benefit to the system and the users. This conclusion was supported by the difference in attitude of the controllers before and after the experiment and by the improvement in performance as the experiment progressed.

Several specific RNAV functions were introduced and recommended phraseology was presented for each. These functions are briefly described below.

1) Parallel Offset - the capability to fly an uncharted route parallel to an established (charted) route. This capability requires input to the RNAV equipment, specifying direction and amount of offset. The aircraft will navigate to and from the offset on a 45° angle unless otherwise specified.

2) Next Leg Offset - the capability to intercept and fly a specified parallel offset on the next leg (segment) of the RNAV route.

3) Delay Fan - a technique using RNAV to effect a delaying maneuver in lieu of radar vectoring.

4) Resume Navigation - a means of returning an RNAV - equipped aircraft to its charted route, after it has been radar vectored.

5) Cancel Offset - an instruction which returns an aircraft from an offset to its established route.

6) Direct to Waypoint - an instruction which causes the aircraft to navigate directly from present position to a specified waypoint.

The training phase of the simulation required approximately 40 hours of simulation time during which five controller teams were trained in the use of RNAV maneuvers. Simulation was continued until their performance in the lab and the data measures taken during each run indicated that the training curve had leveled off.

A further measure of the effect of training and experience was the result of a compilation of answers to a controller questionnaire prior to training, after training, and after the experiment itself. The questions concerned what the reaction of controllers to implementation in the real-world would be, whether RNAV would really work and should be required, if RNAV would make the controllers job easier, if RNAV would improve capacity, etc. In almost all cases the average responses progressed from negative in the pre-training period to slightly positive at the post-training point to more positive after completion of the experiment. Similar attitudes have been encountered in flight test situations with controller participation.

Controller training must include not only the use of RNAV procedures and phraseology, but the recognition and understanding of RNAV equipment capability and the pilot workload associated with various maneuvers. Although the anticipated gradual implementation of RNAV (see Section 5.4) should allow the development of skill in the use of RNAV procedures over a period of time, a dedicated training program will be required to insure that the proper level of controller familiarity will be available to insure an orderly evolution of an RNAV environment. From discussions with the FAA Office of Personnel and Training, it was concluded that an initial period of dedicated RNAV training at the Academy in Oklahoma City would be required in order to provide each radar terminal with core personnel trained in terminal area RNAV procedures. Subsequent instruction would then be provided through routine on-the-job training. Training in enroute RNAV procedures can be accomplished through individual study based on Air Traffic Training Refresher Units published periodically as part of the National Air Traffic Training Program. Two such refresher units on RNAV have been published to date, but they would have to be modified and expanded to reflect the RNAV implementation plan which is adopted.

It is estimated that development of a 40 hour RNAV course at the academy would cost $6633, based on the current cost of developing similar programs, and that annual course maintenance cost would be $8072. If it is assumed that two controllers from each of the 194 TRACONs and TRACABs estimated to be in commission in 1985 [14] would be required to attend one 40 hour course, then twenty-two classes of 18 controllers each would be required to accomplish the initial training at an average per diem rate of $33 and average travel of $250, total initial training cost including course development costs would be $218,691.

5.2.2.3 Controller Comments

An appraisal of the use of RNAV and VNAV in terminal area ATC operations was made by a group of five field controllers who participated in the real time simulation activity at NAFEC [11]. Their remarks, which are given in Appendix H, tend to confirm the results and conclusions presented in this section and other sections of this report.

5.2.3 ATC Automation

The impact of the implementation of RNAV on ATC automation was analyzed in Section 4.4. Six areas in ATC automation were determined to exhibit potential for impact in one or more of the RNAV implementation phases. The terminal area ATC facets impacted include the communication and definition of RNAV routes to the ARTS system, the conflict prediction problem, and arrival aircraft metering and spacing (M & S). The enroute areas impacted also include the definition of RNAV routes and the conflict prediction problem, as well as enroute flow control.

The primary impact concerns computer system core requirements. The enroute core and terminal area requirement due to the implementation of RNAV will incur an additional cost of $258,000 to support a mixed VOR/RNAV environment. However, the core requirements for an all RNAV environment are $174,000 less than the current requirements.

5.2.4 Airspace and Airport Capacity

Several studies have been conducted which relate to the impact of RNAV on airspace capacity. Route width effects were analyzed in a route width/capacity study [5], in the design of a high altitude enroute charted RNAV structure [4], and in the design of terminal area RNAV structures [2]. Fast time simulation was utilized as a design tool for the high altitude enroute charted RNAV structure. The basic simulation outputs were route segment loading and identification and categorization of conflicts. Two levels of RNAV structure were analyzed. The first was a 185 airport pair structure and the second a 429 airport pair structure which was evolved later in the design process. The traffic sample used in the analysis was based on the 1969 peak day IFR data [23]. The 185 airport pair structure provided RNAV routes for 41% of the traffic sample, and the 429 airport pair structure accommodated 67% of the traffic sample.

Figure 5.6 is a summary of common route, non-common route, and total conflicts as a function of percent of traffic on RNAV routes. The conflict count from the 429 airport pair simulation is normalized to the 185 airport pair traffic level. It can be seen from Figure 5.6 that the total number of conflicts decreased with increase in percent RNAV traffic, which is an indication of increased capacity. The common route types include overtake and head-on conflicts and the non-common route types include intersection, merge, diverge, and proximity conflicts. (The conflict types are described in detail in Reference 12). The change in the number of common and non-common route conflicts with change in percent RNAV mix is due to the fact that the VOR and RNAV structures are completely independent but overlaid upon one another. As traffic is diverted from the VOR to the RNAV structure, (say 25% RNAV), fewer common route conflicts would occur on the VOR structure due to reduced density and the difference would not be made up by common route conflicts on the RNAV structure because of even lower density, since number of conflicts vary roughly as the square of density [12]. On the other hand the number of non-common route conflicts can be expected to increase because the two route structures intersect profusely.

The total number of conflicts is less for 100% RNAV traffic than for 100% VOR because the RNAV is a more ordered structure. Increased use of parallel routes would drop the common route conflict count even more, at the expense of increasing intersection type conflicts. The latter are usually more cheaply resolved from a time and fuel viewpoint, however. They also require less controller time to solve, although they may require more intense surveillance to insure timely detection of a developing conflict. The level of non-common conflicts is higher on the 429 airport pair structure since it is a more complex structure than the 185 airport pair structure, and therefore has more intersecting routes.

The impact of VNAV on airspace capacity was analyzed in Section 4.5 and it was concluded that, with rare exceptions, the use of fixed gradient VNAV routes as an airspace design tool is not productive from a capacity viewpoint. Furthermore the 2D/3D real time simulation described in Reference 11 indicated that there are no advantages apparent in an airspace based upon either fixed VNAV gradients or "stacked" VNAV routes and that there are disadvantages to both the controller and the user. It was also found that fixed gradient VNAV departures were significantly penalized in terms of time to transit the terminal area compared with either radar vectored flights or RNAV equipped aircraft. Utilization of pilot selected VNAV gradients had no impact on system operation, but provided significant benefit to the user. It should be emphasized however, that airspace design should accommodate the pilot-selected use of VNAV to the extent practical because of the operational and economic benefits available.

The terminal area RNAV design concept was tested in real time simulations at NAFEC [9,11]. The primary objectives of the first simulation were to evaluate controller workload and to determine if capacity would decrease in a mixed VOR/RNAV environment. The results indicated that operation rates remained essentially constant (with a constant demand traffic sample) while controller workload decreased.

The simulation described in Reference 11 was structured to measure any changes in capacity (either increase or decrease) which occurred with the introduction of various mixes of VOR and RNAV traffic. It was found that RNAV arrivals experienced a significant decrease in holding delays, a decrease in time in system and an increase in operation rates, thus indicating an increase in capacity. No changes in departure delays or operations rate were observed.

In the 4D payoff analysis in Section 3.4, it was concluded that the use of 4D RNAV in M & S terminals can have a large impact on terminal area airspace capacity. Estimates of hourly IFR arrival capacity which were developed for each of eight major airports in 1984, are itemized in Table 5.20.

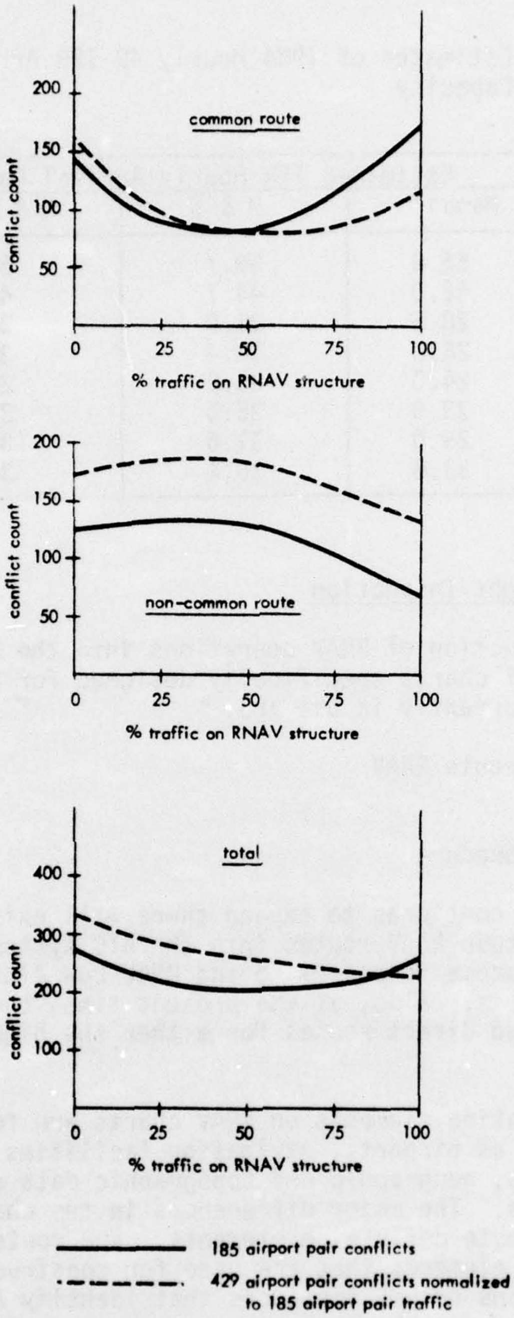

Figure 5.6 Conflict Count vs % RNAV Mix

Table 5.20 Estimates of 1984 Hourly 4D IFR Arrival Capacity

Airport	Estimated IFR Hourly Arrival Capacity		
	Manual	M & S	M & S + 4D
ORD	55.0	59.7	62.9
JFK	42.0	44.7	46.4
LGA	28.5	31.0	32.8
EWR	28.0	30.4	32.1
PHL	24.0	25.8	26.9
MIA	33.0	35.5	37.2
DEN	29.0	31.6	33.4
SFO	33.0	36.4	38.8

5.2.5 Charting and Flight Inspection

The limited introduction of RNAV operations into the ATC system has produced a new series of charts specifically designed for RNAV users. Those RNAV charts which are currently in use are:

High Altitude Enroute RNAV
RNAV SID
RNAV STAR
RNAV Approach Procedure

As the use of RNAV continues to expand there will exist a requirement to introduce more low altitude RNAV routes into the ATC system. As these routes are developed it will become necessary to add RNAV Low Altitude Enroute Charts to the list of RNAV charts. Also, at the present time, there is no satisfactory chart for RNAV preplanned direct routes for either the high or low altitude route structure.

Many of the information elements on RNAV charts are found also on current VOR charts. Such items as airports, navigation facilities and frequencies, communication facilities, geographic and topographic data are all common to both RNAV and VOR charts. The major differences in the charts can be attributed to the routes and the route definition elements. VOR routes are located over-lying VOR radials. The elements that are used for constructing the routes are VORs and VOR intersections or DME distances that identify ATC reporting points, and omni-bearing values for each of the route segments. Other information elements which may appear on the chart that are associated with the VOR route segments are as follows:

- Minimum Enroute Altitude (MEA)
- Minimum Crossing Altitude (MCA)
- Minimum Obstruction Clearance Altitude (MOCA)
- Maximum Authorized Altitude (MAA)
- Distance Between VOR Stations
- Route Segment Distance
- Approach Minimums and Profile View

All of these listed elements are necessary on RNAV charts as well as VOR charts. The major differences between the VOR and the RNAV charts are in the route defining elements. In the RNAV structure the waypoint and its associated name becomes the major route definition element. The waypoint itself should be designated by the two techniques described in Section 5.3.4. One other, and usually lesser used, route defining element may be found on RNAV charts. This is the RNAV intersection. The RNAV intersection is formed by either a distance and bearing from a waypoint or the intersection of the bearings from each of two waypoints. An additional information element that is needed to define the route is the bearing to or from the waypoint. Once the route has been defined it is sometimes necessary to identify waypoint change points along the route. These points are defined by a distance from the waypoint and they are placed on the chart when the waypoint change must come at a point other than the midpoint of a route segment. This can be caused by a number of reasons such as facility coverage, unusable signals, frequency protection, etc. In developing an RNAV route, considerations of route width relative to the reference facility are different than VOR route width criteria. However, this has a considerable impact upon ATC procedures but not upon charting.

The use of preplanned direct (PPD) RNAV routes poses some major charting problems. Preplanned direct routes will be used primarily in the enroute phases of flight so only that aspect of PPD routes will be considered in this discussion. At the present time, through the provisions of Advisory Circular 90 - 63[62], it is possible to file an RNAV PPD flight plan. However, due to the uncertainties of VORTAC coverage along the route and the RNAV route width variations discussed in Advisory Circular 90-45A, the PPD route must be entirely within ATC radar coverage. Consequently, the filed altitudes, waypoints and route segments between waypoints must be carefully chosen to assure radar coverage. It is assumed that this requirement will continue to be applied until increased automation and flow control are realized, and area flight checking is accomplished.

Flight checking is currently accomplished as a part of the procedure for the implementation of new routes. An additional flight checking requirement will develop in the implementation of RNAV routes in accordance with the route development and implementation process described in Section 5.4. The evolution to an all-RNAV environment will involve both the implementation of the total optimum RNAV structure on a gradual, individual route basis, and the implementation of an increasing use of preplanned direct routes. The flight checking process must therefore be structured to accomplish two objectives: (1) the implementation of individual routes on a demand basis, and (2) eventual flight checking of the entire CONUS on an area basis to define acceptable VORTAC coverage for random preplanned direct routes.

Although specific requirements exist for RNAV charting and flight inspection, the gradual implementation of RNAV routes should cause an impact little more than that of current continuing requirements.

5.2.6 System Impact Summary

A summary of the impact of RNAV on the ATC System is given in Table 5.21. Costs and savings for the period from 1982 to 2000 were computed in a separate study [14], and are based on the assumed implementation scenario described in Table 5.17. Savings and costs are also presented in terms of their present (discounted) value, based on guidelines promulgated by the Office of Management and Budget [63]. The ATC system benefit to cost ratio for the time period of 1982-2000 is computed to be 9.9.

Table 5.21 ATC System Impact Summary

			1982-2000 Savings Total	1982-2000 Savings Present Value	1982-2000 Costs Total	1982-2000 Costs Present Value
VORTAC REQUIREMENTS	**Terminal Area (Maintenance)**	Additional VORTAC requirements are nominal compared with F&E planned budget. $2.3 million per year savings due to reduced number in terminal areas. Additional savings available in removal of high altitude VORTACs should offset new station costs and result in overall savings.	$36.1M	$8.0M		
	Enroute (Implementation and maintenance)				$2.4M	$0.8M
CONTROLLER PRODUCTIVITY	Terminal Area	Controller workload will decrease and productivity will increase through use of RNAV procedures both enroute and in the terminal area. Controllers and pilots can function efficiently in a mixed VOR/RNAV environment, and productivity increases will be realized during the transition period from VOR to RNAV.	$26.4M	$8.0M		
	Enroute		$422.0M	$120.7M		
IMPLEMENTATION	Controller Training	Controllers must be trained in use of RNAV procedures to insure orderly evolution of RNAV and realization of user and system benefits			$19.8M	$13.0M
	ATC Automation	Initial cost of $258,000 would be reduced to a savings of $174,000 in all-RNAV environment, allowing use of increased core capacity for other system growth features.				
	Charting and Flight Inspection	Charting and flight inspection will be a continuing routine requirement as routes are implemented from the master route structure.				
	Route Development	An optimum, coordinated master route structure must be designed as a first step toward RNAV implementation.				
	Airspace Capacity	Capacity will be increased in terminal and enroute structures through use of 2D RNAV and use of 4D in M&S terminals in the transition period as well as in an all RNAV environment.				
TOTAL			$484.5M	$136.7M	$22.2M	$13.8M

5.3 SYSTEM DESIGN CONCEPT

The system design concept described in this section, and the implementation concept described in Section 5.4, are intended to expand, clarify, and modify the concept proposed by the RNAV Task Force, taking into consideration the impact of alternate concepts on the user and the system as summarized in Section 5.1 and 5.2.

5.3.1 Airspace Design

The achievement of the benefits described in the previous sections are dependent upon the implementation and airspace design concept which is essentially based on the Task Force concept, but which has been modified in several ways based on operational and economic assessments of that concept. This sub-section summarizes this airspace design concept in the areas of enroute design, terminal area design, route width requirements, and the application of VNAV, and is intended to complement the discussion on route development in Section 5.4.4.

5.3.1.1 RNAV Enroute Structure Design

An analysis of Task Force concepts, and the development of necessary modifications thereto is described in Reference 4 and 12. The methodology used in the analysis is summarized in Section 2.2.2. The enroute design concepts listed below consist of a summary of the results of the analysis of Reference 4. The overriding principle in RNAV enroute structure design is that an optimum total structure should be developed and used as a basis for the implementation of individual routes.

Terminal Arrival and Departure Waypoints

Terminal arrival and departure waypoints should be aligned in accordance with traffic flow demands. This requires that the design of enroute and terminal structures be closely coordinated.

One-Way Routes

One-way routes should be used where their application will reduce traffic congestion and not as a general rule as proposed by the Task Force. The hemisphere rule for altitude separation should be adhered to except when local conditions indicate an operational advantage may be gained by its suspension. One-way route segments are an effective way to accommodate extended climbs and descents to and from enroute altitude.

Multiple Routes

The Task Force concept of providing for two offset routes between parallel route centerlines is unnecessarily restrictive and results in route

mile penalties. Charted routes should be established to accommodate traffic demand in the most effective manner, considering parallel offsets as a tactical maneuver used in conjunction with all other factors which impact network design effectiveness.

Route Merging and Bending

The first step in RNAV route structure design should be to examine traffic flows to determine both the possibilities for merging and the requirements for multiple routes to handle traffic demand. The appropriate combination of merging, bending, and demerging should be derived from a consideration of minimizing user cost consistent with system requirements. The criterion for minimizing user cost should be flight miles, i.e., route mileage multiplied by projected route utilization.

Intersection and Merge/Demerge Angles

Whenever feasible, intersection and merge/demerge angles should be greater than 10 degrees, particularly in areas of high traffic flow, where the high intersection occupancy time would cause excessive controller workload.

Other Factors

The development of an optimum total enroute structure requires consideration, in addition to the foregoing factors, of such characteristics as intersection densities, waypoint densities, waypoint/intersection proximity and excessive route turning. The Task Force concept of great circle routes between airport pairs should be expanded to include charted alternate weather routes whose segments are great circle routes.

Preplanned Direct Routes

The preplanned direct concept described in Section 5.4.1 places flight planning responsibility on the user and requires the use of existing waypoints, or VORTACs, within the charted RNAV structure.

Route Widths

The ±2.5 nm route widths recommended by the Task Force are not required, and traffic demand can be met with constant ±4.0 nm route widths.

5.3.1.2 Terminal Area Design

Based on the terminal area design analysis described in Section 2.1.3 and 5.1.1, a set of terminal area design guidelines was developed [2]. The following paragraphs present a summary of the guidelines contained in Reference 2.

Arrival and Departure Sectors - The application of the basic design should incorporate consideration of traffic distribution demand as well as runway orientation constraints. Similarly, the number and size of departure and arrival sectors should be varied as necessary to accommodate traffic demand, rather than being constrained to equal size octants, as recommended by the Task Force. Metroplex areas require even further modification of the Task Force Design. In these areas it may be necessary to abandon the alternating arrival and departure sector concept in favor of parallel traffic corridors in order to minimize undesirable altitude restrictions and excessive route lengths. The concept of using arrival and departure sectors ("wagon wheel") in designing terminal area routes should be used as a basic design tool for most medium and high density terminal areas. The size and orientation of these corridors should be based primarily on the direction and density of traffic flow. The rigid specification of the location, size and orientation of the corridors, such as the octant concept suggested by the RNAV Task Force, should not be used since it can create operational penalties such as increased distance flown and additional altitude restrictions in complex terminal areas. In metroplex areas particularly, arrival and departure fixes should be located on the basis of enroute traffic flows, and traffic should proceed to a charted conventional downwind, base and final approach sequence in the most direct manner possible without interference from adjacent terminal routes. Altitude restrictions should be determined from typical aircraft altitude vs along track distance profiles.

Low Altitude Waypoints - The location of low altitude arrival waypoints in the Task Force RNAV terminal area design model (25 nm from the airport) is in general agreement with the location of current radar vector/VOR feeder fixes at most airports. Although the location of low altitude departure waypoints 15 nm from the airport is somewhat closer than usually used today, this closer location does not present any serious problems in developing the terminal route structure. The downwind, base and final approach leg used in the Task Force design within 25 nm of the airport is consistent with current airport traffic patterns, and should be charted. If an operational advantage can be gained by eliminating the downwind, or downwind and base, legs of an approach, then these route segments should be eliminated on an ad hoc basis, through the use of appropriate RNAV instructions.

Low Altitude Routes - The low altitude traffic does not need to be constrained by the octant concept. In most terminal designs it is possible for departing low altitude traffic to proceed direct to their enroute route structure once they pass the low altitude departure fix. Similarly, arrivals can proceed from their point of origin to the low altitude arrival fix without interfering with high altitude traffic flow.

Terminal Area Dimensions - The use of a nominal 45 nm circle centered at the primary airport is a satisfactory conceptual aid in defining the extent of a non-metroplex terminal area. The 45 nm circle does not necessarily have any operational significance however. Consequently in actual terminal area design, operational considerations concerning the location of terminal enroute boundaries should take precedence over the use of the conceptual

45 nm boundary. The concept of defining the metroplex terminal area by encircling each airport with a 45 nm ring and then encircling all the 45 nm rings with one large ring, as recommended by the the Task Force, is not feasible since in congested regions such as New York since the size of the large ring would be excessive. It is necessary in these metroplex areas to limit the extent of the terminal area by considering the location of all major airports within the metroplex and the proximity of adjacent terminal areas, and establishing a ring slightly larger than 45 miles which will accommodate the necessary arrival and departure waypoints.

Vertical Design - A vertical gradient of 300 ft/mile for arrivals, consistent with the Task Force recommendations is acceptable for all aircraft. Above 10,000 ft., descent gradients of 400 ft/mile may be used for high speed descents by high performance aircraft. The Task Force recommended departure gradient of 400 ft/mile is not acceptable for all aircraft at all altitudes encountered in the terminal area. An altitude envelope based upon aircraft performance is more desirable than a single departure gradient value. The following envelope which is based upon aircraft performance was used in several of the terminal designs in Reference 2 and should be used as a general guideline.

Altitude	Gradient
0-10000 Ft.	300-550 ft/mile
10000-18000 Ft.	150-350 ft/mile
18000-25000 Ft.	100-200 ft/mile

Fixed gradient VNAV routes should not be utilized, but the 2D design should incorporate vertical separation for crossing routes which is sufficient to allow pilot selection of VNAV descents. Vertical departure envelopes for higher performance aircraft, whose minimum gradient is higher than those listed above, should be utilized when shorter departure routes will result.

Route Locations - Most terminal areas are currently structured in a wagon wheel or spoke type flow pattern with fixed arrival and departure points. However, most spokes are not of equal size nor are they spaced in an octant pattern. In Phase 1 all RNAV routes within the terminal maneuvering area (inside of the low altitude arrival and departure fixes) should overlie the basic radar vector routes. Outside of the terminal maneuvering area, RNAV routes should be established in areas where user benefits will accrue. User benefits include shorter route lengths and a minimum of restrictions during climb and descent. The Phase 2 2D terminal designs must be able to accommodate both conventional radar vector/VOR and 2D RNAV traffic. This represents a considerable constraint upon the design. The flow patterns for this transitional time period should be based upon the Phase 3 terminal design, which should be created prior to the development of the Phase 2 design. The location of feeder fixes and departure fixes should be near those created in the Phase 3 design but moved as necessary to accommodate VOR traffic. Traffic in the terminal maneuvering area should generally conform to the Phase 3 design.

The recommended terminal design procedure begins with the development of the horizontal projection (or ground tracks) of the arrival and departure routes to all major airports in the terminal area. The first task in developing the horizontal design is to define the center and the lateral extent of the terminal area design. For most terminals which have a single major airport, the center of the major terminal airport can be used as the center of the terminal complex. Occasionally in a metroplex area this technique is not satisfactory.

Once the center of the terminal area has been determined, the terminal area, for design purposes, is defined by a radius of approximately 45 nm. For metroplex areas it is sometimes necessary to adjust this radius value to accommodate all airports in the area, but without infringing upon adjacent terminals or metroplex areas. Within the terminal complex two areas are defined. One is the terminal transition area and the second is the terminal maneuvering area. Generally, the area within 15-20 nm of the airport contains the terminal maneuvering area while outside of this distance is the terminal transition area. Routes in the terminal transition area remain fixed no matter which active runways are being used at the airports within the terminal area. Conversely, the routes in the terminal maneuvering area do change as the active runway in use changes. Once the terminal maneuvering area and the terminal transition area have been defined the traffic flows can be used to establish the arrival and departure routes to both primary and satellite airports. It is often desirable to locate an arrival-departure sector boundary along a major traffic flow direction in order to keep arrival and departure routes as short as possible.

Gradients for the 2D routes should be based upon the performance characteristics of several aircraft types under varying conditions. The descent gradient is nominally a constant at 300 feet/mile for descent operation below 10,000 feet. Above 10,000 feet the 300 ft per mile gradient approximates the fuel optimum standard descent and 400 ft per mile gradient approximates the time optimum high speed descent. Descent profiles should accommodate this range. The climb profiles vary widely depending on aircraft type, ambient temperature, aircraft weight and climb airspeed. The vertical route design is accomplished by utilizing a vertical profile plot, for each proposed route, of altitude versus along track distance, with arrival routes being plotted first, at a constant 300 feet/mile. Departure routes are designed which will accommodate the lowest performing aircraft. Additional departure routes are then designed which will either allow unrestricted climb or provide shorter departure routes for aircraft with a specified minimum performance capability.

5.3.1.3 Route Width Requirements

The route widths required for the implementation of routes in the terminal and enroute strutures are given in Table 5.22.

Table 5.22 Route Width Requirements*

	Terminal	Enroute
Phase 1	±2.0 nm [a]	in accordance with 7110.18[38]
Phase 2	±2.0 nm [a,b]	±4.0 nm
Phase 3	±2.0 nm [a,b]	±4.0 nm [b]

* does not include additional airspace for slant range error, which is discussed in Section 5.3.6
a-or ±4.0 nm depending upon distances from VORTAC[38]
b-change from Task Force recommendation

5.3.1.4 VNAV Operational Concept

As envisioned by the RNAV Task Force, VNAV, or 3D RNAV, would provide the following additional features over RNAV:

- the capability for an aircraft to climb or descend to a desired altitude, reaching that altitude at a pre-selected point in space.
- development of routes within terminal airspace with vertical profiles to provide the airspace planner a tool for optimizing use of airspace.
- enhance safety in instrument approaches by providing vertical guidance to noninstrumented runways and by permitting the programming of selectable climb/descent profiles.

The Task Force envisioned wide spread use of VNAV both enroute and in terminal areas, with 3D capability required in the high altitude enroute airspace in the post-1982 time period. A summary of the Task Force recommended VNAV concept is given in Table 5.23.

Implicit in the Task Force VNAV concept is the expectation that the establishment of 3D routes and procedures will be benefical to both the ATC system and the users. Potential benefits identified by the Task Force and comments on those benefits are discussed below:

1) Increased flexibility for the controller due to ability for aircraft to arrive at an assigned altitude at a specified point in space

2) Economic benefit to the user in the ability to optimize time and fuel through adherence to a preplanned vertical profile

   The economic benefit to the user was found to be dependent upon an airspace design with sufficient flexibility in the vertical plane to allow a variety of climb and descent profiles [2,12] rather than imposing a sub-optimum fixed gradient profile.

3) Improved airspace utilization through specified vertical paths.

Airspace utilization using fixed gradient VNAV was analyzed in Section 4.5 and it was concluded that the opportunity to improve airspace utilization with fixed gradient VNAV routes occurs so seldom in the terminal area route design process that it does not warrant serious consideration.

A concept of "stacked" VNAV routes for intercept of parallel precision approach paths was analyzed in the simulation study described in Reference 11. It was found that this concept is not desirable from either an operational or an airspace capacity viewpoint. Therefore a flexible VNAV concept is recommended which will allow aircraft so equipped to obtain economic benefits through ad hoc selection of 3D gradients, but which allows 2D equipped aircraft to fly in the same airspace.

Departure vertical envelopes should be provided to accommodate all aircraft using the terminal area. Additionally, departure envelopes which will provide shorter routes for the higher performance aircraft should be provided. These routes could be used by both 2D and 3D equipped aircraft, and would be defined in the vertical plane by a "floor" of altitude restrictions (and an occasional altitude "ceiling") to insure procedural separation from crossing routes. Any aircraft capable of the required minimum climb performance could utilize these departure routes. There would be no penalty imposed on the lower performance aircraft since the design would be optimized for minimum departure route lengths, coupled with economical descent profiles, which accommodate all aircraft. The design is therefore optimized for both route length and altitude profiles for both 2D and 3D equipped aircraft.

Pilot selection of 3D descents within the constraints of crossing altitude restrictions would allow user optimization of either fuel consumption or time. The use of 3D descents, with the descent angle and speed selected by the pilot, could improve either fuel or time performance as compared with the normal 2D procedural descent procedures. Altitude restrictions at intersections of routes would be specified to accommodate the separation requirements of 3D route crossings. As discussed in Section 4.5.4, 3D crossings generally require more vertical separation then 2D, although in some cases the 2D case requires more.

A summary of the recommended VNAV operational concept is given in Table 5.24.

5.3.2 RNAV Airspace Definition

The Task Force recommended that RNAV be the system of navigation in the high altitude enroute structure and in selected high and medium density terminals in Phase 2 and 3, and this recommendation is also included in the implementation concept presented in this report, even though the timing of the implementation phases would be determined by user demand. The list of terminals

was based on traffic forecasts and is given in the Task Force Report [1]. The terminal area design concept described in Section 5.3.1.2 results in terminal areas with an approximate radius of 45 nm. In order to prevent an undue penalty to low cost general aviation aircraft which may operate at other than the primary airports within the terminal area (see Section 3.5), terminal areas should be defined in a manner similar to that in which terminal control areas (TCA) are now defined. In that manner, RNAV equipment would be required only for operation at primary airports, and a few airports in close proximity to the primary airports. A low altitude path to other airports would then be available without the requirement for RNAV.

5.3.3 Turn Anticipation

The issue of turn anticipation is critical because of its effects on the complexity of RNAV equipment and on the cockpit procedures necessary to reliably provide for anticipation stems from protected airspace considerations. In order to compensate for overshoots, current procedures provide an additional 2.0 nm protected airspace for 10 nm past the turn point [38]. It would be desirable from an airspace viewpoint to require all aircraft to anticipate turns to such a degree that only minimal overshoot would occur and no additional protected airspace would be required.

Overshoots at turn points in low and high altitude enroute operations are, for the most part, insignificant, since most enroute turn angles are small. Overshoots at turn points in terminal area operations can be critical, however, due to the fact that most turns are of sufficient magnitude to cause large overshoots and that the airspace is crowded.

During the General Aviation Flight Test program described in Reference 7, data was recorded on turn overshoots without anticipation and with a method of procedural anticipation. Simulation experiments reported in Reference 8 also included turns with both procedural and automatic anticipation.

The results of these tests indicate that the use of some method of turn anticipation will obviate the need for additional protected airspace and that a procedural technique, in lieu of automatic, is an acceptable minimum requirement. AC90-45A [19] suggests a method of procedural turn anticipation wherein the turn is anticipated by an amount equal to one nautical mile for each 100 knots of ground speed. Tests have concluded that the technique is acceptable, but additional tests are required to determine the full range of acceptable techniques.

5.3.4 Waypoint Standards

The RNAV concept involves both charted and pre-planned direct routes whose segments or, in some case the entire route, are great circle. A variety of navigation sensors, ranging from VORTAC to self-contained to long range aids will be utilized. RNAV systems will range in complexity from single rho/theta analog computers to sophisticated digital multi-sensor dead reckoning systems. The charting of waypoints is necessary for the optimum use of these routes by pilots with the total range of airborne equipment.

Table 5.23 Task Force VNAV Concept

	Phase 1	Phase 2	Phase 3
High Altitude Enroute	no 3D routes established	establish vertical profiles to accommodate A/C equipped with 3D	3D capability required for enroute transition
Low Altitude Enroute	no 3D routes established (may be assigned to aircraft equipped with 3D)		
High Density Terminals		establish 3D arrival procedures with fixed descent gradients to all airports in terminal area	Preferential treatment to aircraft equipped with 3D
Medium Density Terminals	establish 3D departure procedures to meet user needs	establish 3D arrival procedures to meet user needs	preferential treatment to aircraft equipped with 3D
Low Density Terminals		establish 3D arrival procedures to meet user needs	
Approaches - All Airports	establish 3D approaches to the extent practicable		

Table 5.24 VNAV Operational Concept

	Phase 1	Phase 2	Phase 3
High Altitude Enroute	no 3D routes established	establish procedures to allow pilot selection of 3D descent for A/C equipped with 3D	establish procedures to allow pilot selection of 3D descent for A/C equipped with 3D
Low Altitude Enroute	no 3D routes established		
High Density Terminals	establish departure envelopes in which optimum climb profiles may be selected to meet user needs	establish procedures to allow selection of 3D descents for A/C equipped with 3D	
Approaches - All Airports	establish 3D approaches to the extent practicable		

An analysis of waypoint location, waypoint designation, facility selection, parallel offset considerations, waypoint charting, and route definition was conducted as described in Section 2.1.1. The results of the analysis indicated that the most acceptable system is a dual designation system consisting of the radial/distance and pronounceable five alpha techniques.

Radial/Distance System

The radial/distance system is a full 360° radial grid system with 1 nm radial waypoint granularity. For example, 27213 would completely designate the waypoint located on the 272° radial at 13 nm from the VORTAC. This system combines all the advantages of the clock grid and the cardinal radial grid with the added advantage of increased resolution. This designation technique provides 46,800 potential waypoints within the coverage area of each "L" facility (40 nm radius). This resolution offers two additional advantages. First, the charting and utilization of waypoints can be done with varying resolutions depending upon the specific requirements. Second, as can be seen from the preceding figures, the density of waypoints is proportionately larger in the proximity of a VORTAC, which is typically coincident with terminal area operations.

The Radial/Distance system would also incorporate double designation requirements for waypoints requiring greater accuracy than the 1°/1 nm capability of the basic grid. For example, MAP 13/93.3,0.3 would designate the missed approach waypoint located on the 93.3 radial, 0.3 nm from the VORTAC. This system is inherently advantageous to the low capability RNAV user since the bearing and distance from a VORTAC, which is the basic input to the RNAV computer, are included in the charted waypoint information block and are communicated verbally by the controller in the case of impromptu waypoints.

Pronounceable 5 Alpha Waypoint Designators

The Pronounceable 5 Alpha technique names all RNAV waypoints with a five letter combination which can be pronounced in spoken English for communication purposes, charted for geographic orientation purposes and utilized in both the airborne and ground system computers. For example:

Fenner	=	FENER	Mesquite	=	MESKY
Camerron	=	CAMON	Cabin Creek	=	CABIN
Chapin	=	CHAIN	Ruskin	=	USKIN

Assuming that two character positions of the available 5 character slots are reserved for vowel sounds results in more than enough 5 letter combinations to handle not only the existing waypoint code requirements but includes a growth capability on the order of 70 times the current requirements. At the present time it is the FAA's stated policy [62] to assign five-character pronounceable words to all waypoints. This includes renaming all existing route waypoints, SIDs/STARs and IAPs other than the waypoints which correspond to facility locations, which will continue to be referred to by their appropriate 3 letter designators (e.g., Robbinsville-RBV, etc.). As planned, these waypoint names will be the only code used throughout the system for communications,

navigation computer inputs and depiction on aeronautical charts. The following is a reproduction of the current FAA implementation plan stated in Reference 62 for this technique.

1) All new waypoint assignments for routes, SIDs, STARs and RNAV IAPs will be in five-letter name combinations.

2) Nonredundancy must be maintained in the RNAV system only. Other route intersections or facility identifiers will retain current names and codes, i.e., three-letter or number, two letters.

3) Where a waypoint exists with a name and either a five-or three-character code (except facility idents), such names will be revised to five letters and other codes deleted.

4) Waypoints with less than five-letter names will continue to be used until a need exists for such name assignments for alternate use. However, only the three or four letters will be used and other codings shall be cancelled.

5) Initial change will be in the existing three, four and five letter names which are nonredundant within the RNAV route system by cancellation of existing code assignments on a planned effective date.

6) Other name changes and code deletions to be controlled with charted amendment cycles (28 day interval).

7) IAP waypoint revisions to be started following revision of enroute system.

Impromptu Routes

Impromptu routes (enroute) should normally be communicated using the Pronounceable 5 Alpha waypoint designator. Three distinct cases arise regarding impromptu route definition using waypoint designators. The recommended techniques for the three cases are: 1) impromptu routes based on charted waypoints should be communicated using the Pronounceable 5 Alpha designator, 2) impromptu routes based on uncharted waypoints should be communicated using the Radial/Distance designator for station referenced systems, and 3) impromptu routes using uncharted waypoints should not be used by aircraft whose RNAV system does not have the capability to accept rho/theta inputs unless a capability for converting from rho/theta to an acceptable input format is maintained.

5.3.5 Parallel Offsets

The term "Parallel Offsets" should not be confused with "parallel routes". Parallel routes are defined by their own waypoints, while a parallel offset is defined by a perpendicular distance from a parent route, and does not contain its own waypoints. Parallel routes are established in order to provide for traffic demand, while parallel offsets are to be used tactically to solve

potential traffic conflicts or to provide conflict-free climb or descent paths in an impromptu manner. There are four issues involved in the use of parallel offsets: 1) granularity requirements, 2) paralleling in turns, 3) constant radius turns and 4) climbing and descending offsets. Paralleling in turns includes both the issue of turn anticipation (Section 5.3.3) and the issue of method of determining the offset turn point. The issue of constant radius turns is applicable to both parallel offsets and parallel routes. The following conclusions have been drawn from the results of simulations and flight tests [7,8,9].

- Area navigation systems should have the capability to fly parallel offsets in increments of 1 nm out to 20 nm. The displaced needle CDI method of flying parallel offsets is not acceptable due to linearity and scale limitations.

- Paralleling in turns is a required RNAV function. Constant radius turns are not required to provide separation in turns since high speed differentials encountered enroute are accompanied by gentle turns, while the larger turns required in the terminal area involve lower speeds and lower speed differentials. Procedural paralleling in turns is an acceptable method. The amount by which a turn should be anticipated should be increased by the amount of the offset for an inside offset, and decreased by the amount of the offset for an outside offset.

- When offsets during climbs or descents are used, the offset around a turn should be described as follows:

    a) offset outside a turn point: the offset route shall be at the same altitude as the parent route waypoint at the bisector of the turn angle; the offset route shall be defined in one of the following ways:

        1) a fixed vertical angle (less than the parent route VPA) which emanates from the intersection, in the horizontal plane, of the offset route and the bisector.

        2) it may remain in the plane of the parent route (same VPA) until abeam the waypoint, level off at waypoint past the turn, and then continue in the parent route plane.

    b) offset inside a turn point: the offset route shall be defined in one of the following ways:

        1) a fixed vertical path angle (greater than the parent route VPA) which emanates from the intersection, in the horizontal plane, of the offset route and the bisector.

        2) a vertical path angle the same as the parent route VPA prior to the intersection, in the horizontal plane of the offset route and the bisector, and a larger VPA after the turn which allows interception of the parent route VPA prior to the next waypoint.

The airspace requirements for 3D offsets is discussed in Section 4.5.4.

5.3.6 Slant Range Correction

Slant range correction is required for all 3D RNAV systems and for 2D systems operating above 12,500 ft. MSL except when less than 2,500 ft AGL. The resolution of the station altitude input for slant range correction should be 1000 ft.

In the low altitude enroute structure, with route widths ±4 nm, no additional protected airspace is required to compensate for the effects of slant range error. In the terminal area, between 8000 and 12,500 feet, within ±8 nm along track from the tangent point, additional protected airspace is required on the VORTAC side of the route for tangent point distance of 2.0 to 5.0 nm. The additional protected airspace should extend for 8.0 nm along track beyond the VORTAC for one way routes and for 8.0 nm along track on either side of the VORTAC for two way routes, as illustrated in Figure 5.7. Segregation of route width extensions by altitude bands is possible in an RNAV terminal area, since altitudes are assigned to SID/STAR waypoints. A detailed analysis of the effect of slant range error is given in Section 4.1. Analysis of seven terminal area designs [2] determined that the use of additional airspace due to slant range error did not inconvenience the airspace planner and did not impact benefits.

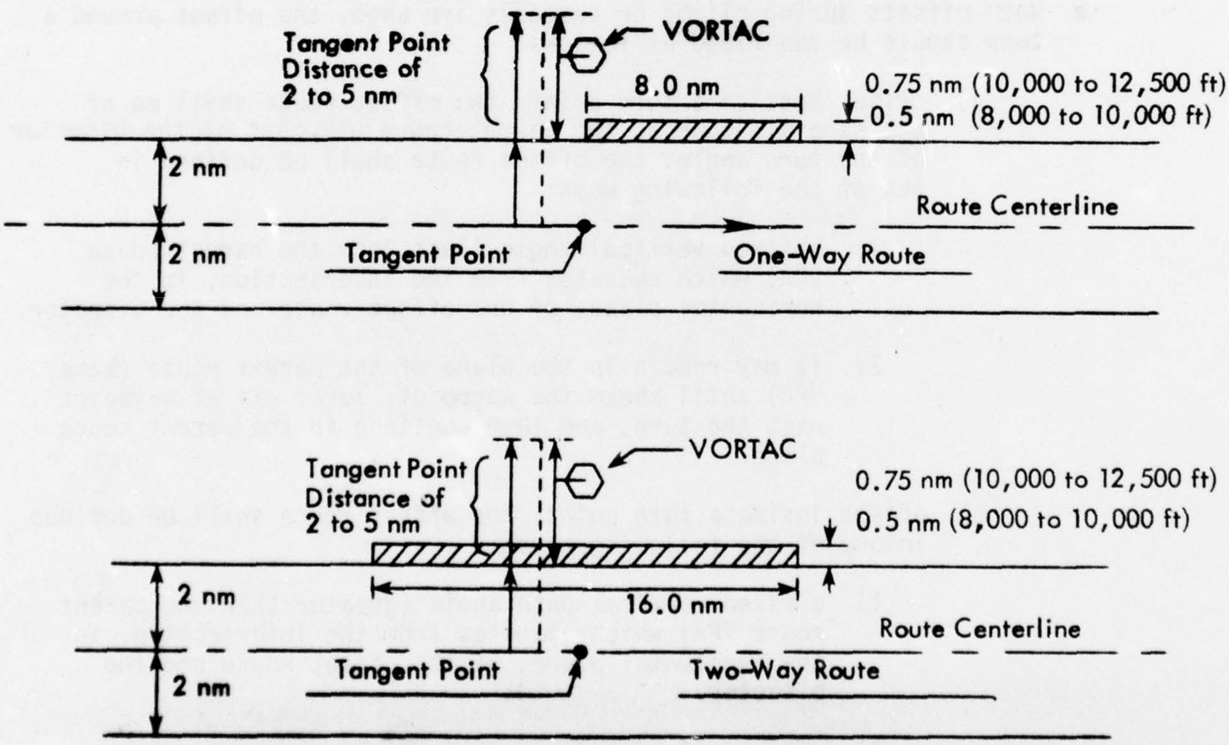

Figure 5.7 Protected Airspace for Slant Range Error in Terminal Area

5.3.7 Equipment Functional Requirements

The RNAV Task Force recommended a set of minimum functional requirements which in general exceed the capability of many RNAV systems currently in production and the minimum functional requirements for 2D and 3D RNAV systems are the subject of continuing simulation, flight test, and analysis. The following listing of functional requirements is representative of the system design concept discussed in this Section and the implementation concept described in Section 5.4. They are extracted from Reference 7 and modified as appropriate by the results of additional analysis reported herein. For controllers to effectively use RNAV, all operations based on like commands should result in like maneuvering of the aircraft over the ground.

5.3.7.1 2D Equipment Functional Requirements

1) Input Data. The area navigation equipments must accept inputs from navigation sensors, descriptions of reference facility locations (where applicable) and waypoint locations. In some types of equipment the desired track bearing may also be an input quantity.

2) Position Determination. The RNAV equipment must determine the aircraft position. Position may be determined either in a station referenced (bearing and distance) coordinate frame or in a geographically referenced (lat/lon) coordinate frame.

3) Track Determination. In systems not requiring the input of desired track angle the desired track must be determined within the RNAV equipment.

4) Cross Track Deviation (or distance). The RNAV system must relate the present position to the desired track in order to derive the cross track deviation.

5) Output Data. The RNAV equipment must provide the distance to the next selected waypoint and the cross track deviation (or distance) as primary RNAV outputs to the display devices.

6) Display Types. The RNAV display may be either linear or angular. However, the flight technical error, which varies with display type and with scale factor, must be properly estimated and included in the accuracy evaluation.

7) Other Sensors. Navigation sensors allowed in the context of "other sensors" specifically includes DME/DME operation and multisensor configurations.

8) Waypoint Storage. A minimum storage capability for more than one waypoint is required for high and medium density terminal area operations. Single waypoint systems are acceptable for enroute operations.

9) Turn Anticipation. Turn anticipation is required, and may be accomplished procedurally or by derivation of commanded track in the RNAV computer.

10) Parallel Offsets. Area navigation systems must have the capability to fly parallel offsets in increments of 1 nm out to 20 nm using a centered needle indication.

11. Slant Range Correction. Slant range correction is required for all systems operating above 12,500 ft MSL except when less than 2,500 ft AGL.

5.3.7.2 3D Equipment Functional Requirements

Vertical navigation is an adjunct to 2D RNAV capability and the following 3D capabilities must be implemented in addition to the requirements of Section 5.3.7.1 in order to attain 3D capability.

1) Input Data. The VNAV equipment must accept input information describing the desired vertical profile. It must provide slope line selection of a gradient angle to a preset altitude at a waypoint or, alternatively, it must be possible to set altitudes associated with waypoints to create the desired slope line reference. In addition, the equipment must provide for leaving or reaching an altitude at a predetermined distance along track to or from the waypoint.

2) Desired Altitude. The VNAV equipment must determine the desired altitude that corresponds to the position estimated within the 2D RNAV computations.

3) Output Data. The VNAV equipment must provide vertical track deviation as an output to the navigation guidance display.

4) Display Types. VNAV displays may be either linear or angular. However, the vertical flight technical error, which varies with display type and scale factor, must be properly estimated and included in the vertical accuracy estimate.

5) Slant Range Correction. Automatic correction of the slant range effect must be provided for in all 3D RNAV systems.

6) Vertical Maneuver Anticipation. When vertical guidance equipment is utilized, vertical maneuver anticipation of some type will be required. The anticipation requirement may be able to be accomplished procedurally in combination with an altitude alert signal.

5.3.8 Accuracy Tolerances

The Task Force Report [1] and AC90-45A [19] list specific error budgets for area navigation systems which will insure the adequacy of the route width requirements. Flight test results [7,8] have indicated that the RSS method of combining errors, as suggested in References 1 and 19, results in errors larger

than those actually experienced due to correlation between various system error elements and between flight technical error and the system error elements. Further analysis is planned for existing and further flight test data which will explicitly define the correlation among the various error elements, and allow a more accurate specification of system error budgets for both ρ/θ and ρ/ρ navigation. FTE will not be considered a part of the resulting error budget for purposes of compliance testing, but will be considered by the airspace planner when combined with system error in a manner which recognizes the correlation between FTE and system error.

5.4 RNAV IMPLEMENTATION REQUIREMENTS

The economic and operational benefits of RNAV to both the user and the ATC system have been identified, and many of the benefits are available now. The enroute fuel and time savings from reduced route lengths will become available as routes are implemented in response to user requirements. Terminal area benefits to the user are dependent upon shorter path lengths, more optimum descent profiles, and conflict-free departure paths with unrestricted climb profiles. The terminal area benefits require the design and implementation of new routes which, in the initial implementation phase, will be implemented as practicable in conjunction with the implementation of enroute RNAV routes. Approach benefits are available immediately in the elimination of circling approaches and access to noninstrumented runways.

If benefits cited in this report are to be realized, a carefully coordinated time-phased systems approach must be employed. A three phase implementation program similar to the one recommended by the task force is required to insure an orderly transition to an RNAV environment. An evolutionary concept is required which will achieve the system design concept with minimum impact on system and user, but which is based on the attainment of the ultimate concept and benefits.

It is particularly important that the design of RNAV structures for high altitude, low altitude, terminal and transition areas be closely coordinated. These designs should be created for the Phase 3 system and the implementation of routes in the transition phases should be based on the total Phase 3 system design to the extent practicable. Flight checking of routes should proceed in accordance with user requirements, but provisions should be made for the development of flight checked area coverage charts which will define areas and NAVAID coverage within which pre-planned direct routes may be eventually utilized without the requirement for continuous radar monitoring.

Investigative work is still required, particularly in the areas of controller display requirements, avionics standards and equipment MOCs, system accuracy determination and compliance criteria, and the development of optimum integrated enroute and terminal route structures. The route structure development to date was for the purpose of assessing RNAV impact and payoff, and although representative of an optimum structure, from that viewpoint, requires considerable expansion and coordination. Task Force recommended research and development efforts which have been completed to date include controller workload in a mixed VOR/RNAV environment, assessment of system and user payoff, development of terminal area guidelines, development of representative terminal area structures for payoff assessment, and development of recommended waypoint designation standards. These studies, as well as partially completed studies in the areas of avionics standards and system accuracy determination, have produced results which allow definition of an RNAV implementation concept in enough detail to allow it to proceed concurrently with other ongoing efforts. A summary of RNAV implementation requirements is given in Table 5.25, and discussed in the following paragraphs.

5.4.1 High Altitude Enroute

An immediate effort should be undertaken to develop and coordinate an optimum high altitude charted RNAV structure, based on the concept described in Section 5.3.1.1, and coordinated with low altitude, terminal and transition designs. Route development guidelines and tools developed by NAFEC should be employed in this process. Existing high altitude jet RNAV routes should be realigned to conform with the optimum total design or eliminated as appropriate. Additional routes should be implemented to meet user requirements as practicable, depending upon fulfillment of flight checking and charting requirements.

Phase 1

In Phase 1, VOR routes should be realigned as required as RNAV routes are implemented from the optimum route structure. Limited pre-planned direct flights will be accommodated, with radar monitoring as required. Flight planning responsibility for pre-planned direct flights will rest with the user, and waypoint selection will be in accordance with the concept described in Section 5.3.4. Pilot selection of 3D profiles will be allowed where not in conflict with ATC specified descent requirements, and tactical use of parallel offsets should be initiated. Limited resectorization should be accomplished to optimize control of traffic.

Phase 2

In Phase 2, 2D RNAV utilizing the charted high altitude structure will be the system, and all VOR routes will be deleted. Procedures should be developed to allow pilot selection of 3D descent and climb profiles. The evolution of the use of pre-planned direct will continue, and complete resectorization will be accomplished for optimization of routes.

Phase 3

Phase 3 is essentially unchanged from Phase 2 except that increased use of preplanned direct will be possible without radar monitoring. The Phase 3 RNAV concept calls for 2D charted RNAV as the system in the high altitude structure with pre-planned direct accommodated according to user requirements. It is anticipated that pre-planned direct flights will use existing waypoints, or VORTACs as waypoints, unless an operational advantage can be gained in using uncharted waypoints. All uncharted waypoints will be communicated by the 5 number rho/theta designator. Non-station-referenced systems that do not have the capability to input rho/theta waypoints should not use impromptu uncharted waypoints unless the capability of converting from rho/theta to an acceptable input format is maintained. Flight planning of pre-planned direct flights will be the responsibility of the user.

5.4.2 Low Altitude Enroute

An immediate effort should be undertaken to develop and coordinate with users an optimum low altitude charted RNAV structure, based on the concept

described in Section 5.3.1.1 and coordinated with the high altitude, terminal and transition designs. Route development guidelines and tools developed by NAFEC should be employed in this process.

Phase 1

Low altitude charted RNAV routes should be implemented from the optimum route structure in response to user requirements. The routes should be based on the optimum total design to the extent practicable and VOR routes realigned as required. All routes should be public use routes unless an operational advantage can be gained. Limited pre-planned direct flights should be accommodated, with radar monitoring as required. Flight planning of preplanned direct flights will be the responsibility of the user and waypoints will be selected in accordance with the concept described in Section 5.3.4. Charted waypoints, or VORTACs as waypoints, should be utilized for pre-planned direct flights. Limited resectorization should be accomplished as required. Tactical use of uncharted parallel offsets should be initiated. Pilot selection of 3D descents and climbs may be utilized where not in conflict with ATC specified descent requirements.

Phase 2

Phase 2 is a continuation of the evolution to wider use of charted RNAV routes and radar monitored pre-planned direct initiated in Phase 1. As RNAV routes exceed the number of VOR routes, unnecessary VOR routes should be deleted, the remaining VOR routes realigned to conform to RNAV routes to the extent practicable, and complete resectorization accomplished to optimize routes. Procedures should be established to allow pilot selection of 3D descents and climbs.

Phase 3

In Phase 3, 2D charted RNAV with a scaled down VOR airway structure will be the navigation system. As automation improvements are implemented and flight checking of areas is accomplished, pre-planned direct flights will be accommodated without the requirement for radar monitoring. It is anticipated that pre-planned direct flights will use existing waypoints, or VORTACs as waypoints, unless an operational advantage can be obtained. All uncharted waypoints will be communicated by the rho/theta designator as in the high altitude structure.

5.4.3 Terminal Area

Terminal area routes should be implemented as quickly as practicable in conjunction with high and low altiude RNAV routes and to overlie radar vector routes. 2D SIDs/STARs should extend from the enroute arrival or departure waypoint to the final approach waypoint or airport departure waypoints. Terminal area designs should be developed as described in Section 5.3.1.2, and routes implemented from these designs to the extent practicable. Route development guidelines and tools developed by NAFEC should be employed in this process. 2D/3D approaches should be designed for all runways, including ILS, to the extent practicable, consistent with IFR requirements.

Phase 1

Design 2D RNAV routes at all high and medium density terminals, coordinating designs with high and low altitude enroute designs. Implement 2D RNAV routes as required in conjunction with high and low altitude enroute implementation. Design 2D RNAV routes for low density and non-radar terminals as required for implementation. Realign VOR/vector paths to accommodate RNAV routes as practicable, or realign RNAV routes if necessary. Pilot selection of 3D descents may be utilized where not in conflict with ATC specified descent requirements. Establish RNAV procedures compatible with M & S terminals when need exists.

Phase 2

Automated metering/sequencing is assumed at selected high density terminals. Design 2D RNAV routes at all low density and non-radar terminals. Implement 2D RNAV routes as required in conjunction with high and low altitude enroute implementation. Realign VOR/vector routes as necessary to conform to 2D RNAV routes. 2D RNAV is the navigation system in high density terminals. Establish procedures to allow pilot selection of 3D descent and climb for A/C equipped with 3D.

Phase 3

Automated metering/sequencing is assumed at high and selected medium density terminals and conflict detection is assumed at all radar terminals. 2D RNAV is the system in medium density terminals. 4D may be required in M & S terminals.

5.4.4 RNAV Route Structure Development

The development of the RNAV route structure will have a direct and immediate impact on several services within the FAA as well as agencies and user groups outside of the ATC system. This impact is expected to start in the very near future, since the first major step required in order to implement RNAV in such a manner as to achieve benefits to the users and the ATC system, is to develop high altitude, low altitude and terminal area route structures for the Phase III implementation period. Development of these structures should be initiated immediately for the following reasons:

- The objective of the Phase III period is to have an optimum master route structure design (for all environments) implemented so that maximum benefits to all parties may be derived. The best and most direct way to accomplish this objective is to design the optimum structure first, and then implement individual routes as demand arises and as flight checking facilities permit.

- Knowledge of the form of the final objective route structure will allow for the orderly formulation and implementation of RNAV operational plans by all parties involved (users and system).

- Route structure development is a long lead-time operation by the very nature of the task, since extensive coordination between users and FAA headquarters and field personnel is required throughout the process. Since the Phase III structure is to be implemented (in part, at least) as the Phase II structure, the final result is needed in a relatively short time.

The impacts expected on the system and other groups as a result of the entire route implementation process will occur both during the route structure development phase, and as the structures are implemented. However, the types of impacts involved will be significantly different in each case as hypothesized below.

Route Structure Development Phase Impacts

Air Traffic Service - FAA Headquarters: Headquarters personnel should be responsible for the entire route design effort for all three environments (high altitude, low altitude and terminal area), and should interact with all other groups involved.

Air Traffic Service - Field Offices: Enroute Center and TRACON personnel will be involved intimately in the route structure development process in order that local airspace allocation, air traffic pattern and demand and restricted noise sensitive area problems are considered. They will also assist in the coordination between SRDS and Headquarters ATS in enroute/terminal interface which will insure a final structure which optimizes user economic benefits.

Systems Research and Development Service: The major role of SRDS is to support ATS in resolving technical issues arising out of the route structure development problem, including the application of enroute and terminal area design techniques and tools, and user benefit optimization techniques, which have been developed. Such issues are also expected to include determination of any additional automation needs for the new route structures, Navaid station requirements and route coverage problems, and avionics standards development.

National Aviation Facilities Experimental Center: NAFEC would be involved in supporting ATS and SRDS in resolving technical issues, as above, including the application of route design tools which have been developed.

Flight Standards Service: AFS personnel should be relied upon to provide Navaid station coverage data for route structure support planning.

Military Organizations and User Groups (Air Carrier and General Aviation): These groups should provide consultation and inputs concerning routing reqirements and suitability of candidate structure designs.

Route Structure Implementation Phase Impacts

Air Traffic Service - FAA Headquarters: Headquarters should be responsible for the piece-by-piece implementation of the RNAV structures as user needs and capabilities demand, and as AFS flight checking progress allows. In the process VOR routes will be deleted or reoriented as user capabilities allow and as need arises for improved airspace organization. All required charting data will be provided to the appropriate government and private agencies. Required video map data shall also be compiled.

Air Traffic Service - Field Offices: TRACON and center personnel will coordinate implementation procedures with Headquarters. Region personnel will receive and process user requests and comments.

SRDS & NAFEC: These services will provide technical support to resolve local implementation problems, and will support automation improvements necessitated by the RNAV implementation process.

Flight Standards Service: Flight Standards will be responsible for flight checking all routes and instrument procedures before actual implementation. Additionally, they will carry out the orderly area coverage flight checking required for implementing RNAV direct flight plans.

Military Organizations and User Groups: Since the implementation schedule is intended to be influenced heavily by user needs, close contacts with these groups will be maintained throughout the route structure design and implementation phases.

Table 5.25

AREA NAVIGATION IMPLEMENTATION CONCEPT

HIGH ALTITUDE ENROUTE (FL180-450)

Phase 1	Phase 2	Phase 3
A.⊕Design an optimum charted RNAV structure to accommodate all the high altitude traffic. Implement routes from the structure in response to user requirements. All routes should be public use routes. Enroute structure design should be coordinated with terminal designs.	A. 2D RNAV utilizing the charted high altitude structure will be the system.	A.*same as phase 2.
B.⊕Realign VOR jet routes as required as RNAV routes are implemented.	B. Delete all VOR routes.	B.*same as phase 2.
C.⊕Limited pre-planned direct flights accommodated, with radar surveillance. All pre-planned direct flights utilize charted waypoints, VORTACs, or radial/distance uncharted waypoints.	C.⊕Pre-planned direct where RNAV routes not designated, with radar surveillance. All pre-planned direct flights utilize charted waypoints, VORTACs, or radial/distance uncharted waypoints.	C.*When necessary automation improvements are made, pre-planned direct RNAV routes will supplement the charted RNAV structure. All pre-planned direct flights utilize charted waypoints, VORTACs or radial/distance uncharted waypoints. Radar surveillance no longer required when route is flight checked.
D.⊕Establish 2D SIDs/STARs for route continuity as necessary. Pilot selection of 3D descent may be utilized where not in conflict with 2D procedural descent requirements.	D.*Establish procedures to allow pilot selection of 3D descent for A/C equipped with 3D.	D.*same as phase 2.
E.⊕Great circle routes as practical-flat earth computation acceptable.	E.⊕All routes great circle unless user/system operational advantage exists - flat earth computation acceptable.	E.⊕same as phase 2.
F. Route widths in accordance with 7110.18 - slant range correction required.	F.⊕Route widths ± 4 nm (constant) - waypoints as in section 5.3.4.	F.⊕same as phase 2.
G. Designate parallel routes when necessary to meet traffic demands.	G. same as phase 1.	G.*same as phase 1.
H.⊕Parallel offsets (uncharted) will be utilized tactically.	H.⊕same as phase 1.	H.⊕same as phase 1.
I. Limited resectorization	I. Complete resectorization for optimization of routes.	I. same as phase 2.

⊕expansion or clarification of Task Force Concept *modification of Task Force Concept

Table 5.25 (continued)

AREA NAVIGATION IMPLEMENTATION CONCEPT
LOW ALTITUDE ENROUTE

Phase 1	Phase 2	Phase 3
A. ⊕Design an optimum charted RNAV structure to accommodate all the low altitude traffic. Implement routes from the structure in response to user requirements. All routes should be public use routes. Enroute structure design should be coordinated with terminals.	A. ⊕same as phase 1.	A. * 2D charted RNAV with scaled down VOR airway structure will be the navigation system.
B. ⊕Realign VOR airways where required as RNAV routes are implemented.	B. Delete unnecessary VOR airways and realign remaining airways to conform to RNAV routes to extent practicable.	B. * same as phase 2.
C. ⊕Limited pre-planned direct flights accommodated with radar surveillance. All pre-planned flights utilize charted waypoints, VORTACs, or radial/distance uncharted waypoints.	C. ⊕same as phase 1.	C. * same as phase 1.
D. Great circle routes as practicable - flat earth computation acceptable.	D. same as phase 1.	D. same as phase 1.
E. * Route widths in accordance with 7110.18 as revised (ref. section 5.3.6). Slant range correction required above 12,500 ft. MSL	E. * same as phase 1	E. * same as phase 1.
F. ⊕Parallel offsets (uncharted) may be utilized tactically.	F. ⊕same as phase 1.	F. ⊕same as phase 1.
G. Limited resectorization.	G. Complete resectorization.	G. same as phase 2.
H. * Pilot selection of 3D descent may be utilized where not in conflict with 2D procedural descent requirements.	H. * Establish procedures to allow pilot selection of 3D descent for A/C equipped with 3D.	H. * same as phase 2.

⊕expansion or clarification of Task Force Concept
*modification of Task Force Concept

Table 5.25 (continued)

AREA NAVIGATION IMPLEMENTATION CONCEPT

TERMINAL

Phase 1	Phase 2	Phase 3
Assumes ARTS Capability at all high and selected medium density terminals.	Assumes metering/sequencing at selected high density terminals.	Assumes metering/sequencing at high and selected medium density terminals and conflict detection at all radar terminals.
A. *Terminal Design Concept (ref. section 5.3.1.2) implemented to extent practicable at all radar terminals.	A. *Terminal Design Concept (ref. section 5.3.1.2) implemented at all radar terminals.	A. * same as phase 2.
B. Design 2D RNAV routes at all high and medium density terminals, coordinating designs with high and low altitude enroute designs. Implement 2D RNAV routes as required in conjunction with high and low altitude enroute implementation. Design 2D RNAV routes for low density and non-radar terminals as required for implementation. Realign VOR/vector paths to accommodate RNAV routes as practicable, or realign RNAV routes if necessary.	B. Design 2D RNAV routes at all low density and non-radar terminals. Implement 2D RNAV routes as required in conjunction with high and low altitude enroute implementation. Realign VOR/vector routes as necessary to conform to 2D RNAV routes. 2D RNAV is the navigation system in high density terminals. Establish climb envelopes to provide shorter departure routes for higher performance aircraft.	B. same as phase 2, plus 2D RNAV is the navigation system in medium density terminals.
C. Pilot selection of 3D descents may be utilized where not in conflict with 2D procedural descent requirements.	C. Establish procedures to allow pilot selection of 3D descent for A/C equipped with 3D.	C. same as phase 2.
D. Establish 4D procedures when need exists.	D. 4D capability may be required at M & S terminals.	D. same as phase 2.
E. ⊕Route widths in accordance with 7110.18, as revised (see section 5.3.6). Slant Range correction required above 12,500 MSL.	E. * same as phase 1.	E. * same as phase 1.
F. Establish 2D/3D approaches for all airports to the extent practicable, consistent with IFR requirements.	F. same as phase 1.	F. same as phase 1.

⊕expansion or clarification of Task Force Concept
*modification of Task Force Concept

6.0 CONCLUSIONS

The results obtained from economic and operational impact analyses, and from various supporting system studies, indicate that the advantages of area navigation to both the users and the ATC system are sufficient to warrant implementation of the area navigation concept described in this report. This overall conclusion is supported by the specific conclusions listed below:

<u>User Payoff</u>

- Substantial economic benefits are available to RNAV equipped users operating in both a high and low altitude 2D charted RNAV structure, and additional benefits are available through the use of preplanned direct routes. These benefits are not dependent upon full implementation of RNAV structures, but may be realized on individual routes as they are implemented. However, these benefits are dependent upon development of a master route structure from which routes are implemented as required.

- Substantial economic benefits are also available to RNAV equipped users operating in an RNAV terminal area environment. While the total savings described in this report are dependent upon full implementation of RNAV routes in the terminal area when a large enough percentage of the aircraft are equipped to warrant changing to an RNAV terminal area design, substantial benefits are available as individual terminal routes are implemented in conjunction with low and high altitude enroute segments.

- The use of pilot-selected 3D descents can result in substantial user savings in both fuel and time, particularly in RNAV terminal and transition areas. These savings are also available now through the use of VNAV in the VOR structure, and are not dependent upon full implementation of RNAV. The use of fixed gradient VNAV routes in a terminal area design imposes user penalties and does not increase airspace capacity. The benefits available in 2D RNAV terminal areas need not be compromised by the use of suboptimal 3D climbs or descents.

- Increased arrival operation rates and reduced arrival delays can be expected in a mixed RNAV/VOR environment, as well as in an all-RNAV environment.

- When properly implemented, the terminal area design concept described in this report will provide significant economic benefits to departing aircraft by providing minimum length departure routes with few climb restrictions.

- 2D and 3D approach procedures will increase safety through elimination of circling approaches, and will provide economic benefits through reduction of distance traveled during transition to approaches.

- The use of 4D time control navigation can provide a significant reduction in arrival delays in M & S terminals, and will provide substantial economic benefits to the user.

- RNAV can directly reduce departure ground delays induced by enroute and transition traffic congestion through the ability to utilize parallel routes. This same ability will allow more optimum altitude assignments.

- The cost of acquiring and maintaining the RNAV equipment required by the operational concept described in this report is nominal compared with the overall benefits available to all classes of user.

System Impact

- Contrary to the concerns expressed by the RNAV Task Force, controllers will be able to function efficiently in a mixed VOR/RNAV environment with reduced workload and with an increase in system capacity.

- A continuing controller training program will be necessary to provide a level of controller familiarity with RNAV procedures which will insure the timely evolution of an all-RNAV environment.

- Lack of slant range correction in RNAV equipment below 12,500 feet will not have an adverse effect on terminal area or low altitude enroute route design.

- The use of pilot selected VNAV gradients will provide significant user benefits while having no impact on ATC system operation.

- The implementation of RNAV will allow substantial savings in VORTAC costs in the terminal area, and the cost to provide VORTAC coverage in the high altitude enroute structure is nominal when compared with the projected F & E budget for Navigation Aids in support of the VOR airways structure. These costs can probably be offset entirely by maintenance savings incurred through the removal of redundant high altitude VORTACs.

- The impact of RNAV on ATC automation is nominal during the transition phase of a mixed VOR/RNAV environment, and the enroute and terminal computer core requirements for an all RNAV structure are less than those for the current VOR structure. This additional capability could then be used for other system growth requirements.

- The increase in airspace capacity necessary to accommodate expected traffic demand in the 1980's can be provided by an RNAV structure with enroute widths of a constant ± 4 nm and terminal route widths of a constant $\pm$ 2 nm or $\pm$ 4 nm depending upon distance from the VORTAC.

- The use of fixed gradient VNAV routes imposes user penalties and generally does not increase airspace capacity. Terminal area routes should be designed to allow pilot selection of 3D climbs and descents.

Operational Concept

- The realization of the benefits available to both the system and the users is dependent upon implementation of the operational concept as described in this report, which is in turn dependent upon early development of a total optimum RNAV structure.

- A critical first step in the RNAV implementation process is the development of optimum, complete master high altitude and low altitude charted RNAV structures. These structures must be closely coordinated with the development of terminal area structures for the appropriate high and medium density terminals. Individual routes should be implemented from the master structures.

- Although further research and development efforts are necessary in the areas of avionics standards, system accuracy, and impact on other elements of the upgraded third generation system, the implementation of the RNAV concept can proceed in parallel with these efforts.

- The system design concept that should be implemented is a modification of the Task Force Concept, which consists of a more flexible terminal area structure, which is optimized for traffic flow and user economics, and charted high and low altitude structures. Preplanned direct flights should not be as widespread as envisioned by the Task Force, and, when utilized, should be based primarily on use of charted way-points and Navaids.

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APPENDIX A

TERMINAL AREA AIRCRAFT PERFORMANCE DATA

The data tables used in the analysis of terminal area altitude restrictions are contained herein. The high speed climb and descent tables list the distance required to climb from sea level to the indicated altitude, or vice versa for descent. The data is taken from Reference 12, and includes the 250 KIAS speed limit below 10,000 feet. The descent data below 10,000 feet was modified for the aircraft when needed, increasing the descent rate to 400 feet per mile (reflecting the more realistic procedure of descending at a lower speed and higher descent rate in the terminal area). Time and fuel data were not used.

The altitude restriction penalty tables list the time and fuel penalties during climb and descent. In each case they represent the difference between the cruise speed and fuel consumption rates at the restriction altitude and at a nominal cruise altitude and weight. The conditions used are listed in the table below:

Table A.1 HIGH ALTITUDE CRUISE CONFIGURATIONS

	For Climb Case			For Descent Case		
Aircraft	Mach	Weight	Altitude	Mach	Weight	Altitude
DC-9	0.77	110 Klb	FL 270	0.77	90 Klb	FL 350
B-727	0.80	160 Klb	FL 270	0.80	140 Klb	FL 350
DC-8	0.80	300 Klb	FL 310	0.80	220 Klb	FL 390
B-747	0.84	650 Klb	FL 310	0.84	550 Klb	FL 390
DC-10						FL 390
F.28						FL 390
Lear 25						FL 410
FH 227						FL 200

Both sets of tables are also provided for the long range descent case for the DC-9, B-727, BC-8 and DC-10.

High Speed Climb/High Speed Descent

Distance - to - Climb/Descend Data

	ALTITUDE	TIME (Hours)	DISTANCE (nm)	FUEL (Pounds)	AIRCRAFT
CLIMB					
	0.	0.000	0.00	0.	DC-9
	1000.	.0064	1.66	88.	DC-9
	2000.	.0128	3.32	176.	DC-9
	3000.	.0192	4.98	264.	DC-9
	4000.	.0256	6.64	352.	DC-9
	5000.	.0320	8.30	440.	DC-9
	6000.	.0392	10.32	528.	DC-9
	7000.	.0464	12.34	616.	DC-9
	8000.	.0536	14.36	704.	DC-9
	9000.	.0608	16.38	792.	DC-9
	10000.	.0680	18.40	880.	DC-9
	11000.	.0922	27.08	1162.	DC-9
	12000.	.1014	30.56	1264.	DC-9
	13000.	.1106	34.04	1366.	DC-9
	14000.	.1198	37.52	1468.	DC-9
	15000.	.1290	41.00	1570.	DC-9
	16000.	.1406	45.78	1690.	DC-9
	17000.	.1522	50.56	1810.	DC-9
	18000.	.1638	55.34	1930.	DC-9
	19000.	.1754	60.12	2050.	DC-9
	20000.	.1870	64.90	2170.	DC-9
DESCENT					
	0.	0.000	0.00	0.	DC-9
	1000.	.0096	2.50	18.	DC-9
	2000.	.0192	5.00	36.	DC-9
	3000.	.0288	7.50	54.	DC-9
	4000.	.0384	10.00	72.	DC-9
	5000.	.0480	12.50	90.	DC-9
	6000.	.0572	15.02	104.	DC-9
	7000.	.0664	17.54	118.	DC-9
	8000.	.0756	20.06	132.	DC-9
	9000.	.0848	22.58	146.	DC-9
	10000.	.0940	25.10	160.	DC-9
	11000.	.1144	31.74	186.	DC-9
	12000.	.1198	33.78	193.	DC-9
	13000.	.1252	35.82	199.	DC-9
	14000.	.1306	37.86	206.	DC-9
	15000.	.1360	39.90	213.	DC-9
	16000.	.1410	41.98	218.	DC-9
	17000.	.1460	44.06	223.	DC-9
	18000.	.1510	46.14	229.	DC-9
	19000.	.1560	48.22	234.	DC-9
	20000.	.1610	50.30	239.	DC-9

High Speed Climb/High Speed Descent

Distance - to - Climb/Descend Data

	ALTITUDE	TIME (Hours)	DISTANCE (nm)	FUEL (Pounds)	AIRCRAFT
CLIMB					
	0.	0.0000	0.00	0.	B727
	1000.	.0060	1.60	121.	B727
	2000.	.0120	3.20	242.	B727
	3000.	.0180	4.80	363.	B727
	4000.	.0240	6.40	484.	B727
	5000.	.0300	8.00	605.	B727
	6000.	.0370	9.86	728.	B727
	7000.	.0440	11.72	851.	B727
	8000.	.0510	13.58	974.	B727
	9000.	.0580	15.44	1097.	B727
	10000.	.0650	17.30	1220.	B727
	11000.	.0774	21.92	1436.	B727
	12000.	.0898	26.54	1652.	B727
	13000.	.1022	31.16	1868.	B727
	14000.	.1146	35.78	2084.	B727
	15000.	.1270	40.40	2300.	B727
	16000.	.1372	44.92	2461.	B727
	17000.	.1474	49.44	2622.	B727
	18000.	.1576	53.96	2783.	B727
	19000.	.1678	58.48	2944.	B727
	20000.	.1780	63.00	3105.	B727
DESCENT					
	0.	0.0000	0.00	0.	B727
	1000.	.0112	2.50	32.	B727
	2000.	.0224	5.00	64.	B727
	3000.	.0336	7.50	96.	B727
	4000.	.0448	10.00	128.	B727
	5000.	.0560	12.50	160.	B727
	6000.	.0662	15.26	182.	B727
	7000.	.0764	18.02	204.	B727
	8000.	.0866	20.78	226.	B727
	9000.	.0968	23.54	248.	B727
	10000.	.1070	26.30	270.	B727
	11000.	.1172	30.48	292.	B727
	12000.	.1274	34.66	314.	B727
	13000.	.1376	38.84	336.	B727
	14000.	.1478	43.02	358.	B727
	15000.	.1580	47.20	380.	B727
	16000.	.1616	49.14	390.	B727
	17000.	.1652	51.08	400.	B727
	18000.	.1688	53.02	410.	B727
	19000.	.1724	54.96	420.	B727
	20000.	.1760	56.90	430.	B727

High Speed Climb/High Speed Descent

Distance - to - Climb/Descend Data

	ALTITUDE	TIME (Hours)	DISTANCE (nm)	FUEL (Pounds)	AIRCRAFT
CLIMB					
	0.	0.0000	0.00	0.	DC-8
	1000.	.0064	1.76	228.	DC-8
	2000.	.0128	3.52	456.	DC-8
	3000.	.0192	5.28	684.	DC-8
	4000.	.0256	7.04	912.	DC-8
	5000.	.0320	8.80	1140.	DC-8
	6000.	.0398	10.90	1366.	DC-8
	7000.	.0476	13.00	1592.	DC-8
	8000.	.0554	15.10	1818.	DC-8
	9000.	.0632	17.20	2044.	DC-8
	10000.	.0710	19.30	2270.	DC-8
	11000.	.0912	25.76	2824.	DC-8
	12000.	.0994	28.62	3058.	DC-8
	13000.	.1076	31.48	3292.	DC-8
	14000.	.1158	34.34	3526.	DC-8
	15000.	.1240	37.20	3760.	DC-8
	16000.	.1344	41.34	4016.	DC-8
	17000.	.1448	45.48	4272.	DC-8
	18000.	.1552	49.62	4528.	DC-8
	19000.	.1656	53.76	4784.	DC-8
	20000.	.1760	57.90	5040.	DC-8
DESCENT					
	0.	0.0000	0.00	0.	DC-8
	1000.	.0130	2.50	59.	DC-8
	2000.	.0260	5.00	117.	DC-8
	3000.	.0390	7.50	176.	DC-8
	4000.	.0520	10.00	234.	DC-8
	5000.	.0650	12.50	293.	DC-8
	6000.	.0766	15.74	339.	DC-8
	7000.	.0882	18.98	385.	DC-8
	8000.	.0998	22.22	430.	DC-8
	9000.	.1114	25.46	476.	DC-8
	10000.	.1230	28.70	522.	DC-8
	11000.	.1514	38.60	630.	DC-8
	12000.	.1568	40.80	652.	DC-8
	13000.	.1622	43.00	673.	DC-8
	14000.	.1676	45.20	695.	DC-8
	15000.	.1730	47.40	716.	DC-8
	16000.	.1788	49.88	734.	DC-8
	17000.	.1846	52.36	752.	DC-8
	18000.	.1904	54.84	771.	DC-8
	19000.	.1962	57.32	789.	DC-8
	20000.	.2020	59.80	807.	DC-8

<u>High Speed Climb/High Speed Descent</u>

<u>Distance - to - Climb/Descend Data</u>

	ALTITUDE	TIME (Hours)	DISTANCE (nm)	FUEL (Pounds)	AIRCRAFT
CLIMB					
	0.	0.	0.00	0.	B747
	1000.	.0056	1.40	260.	B747
	2000.	.0112	2.80	520.	B747
	3000.	.0168	4.20	780.	B747
	4000.	.0224	5.60	1040.	B747
	5000.	.0280	7.00	1300.	B747
	6000.	.0366	9.40	1700.	B747
	7000.	.0452	11.80	2100.	B747
	8000.	.0538	14.20	2500.	B747
	9000.	.0624	16.60	2900.	B747
	10000.	.0710	19.00	3300.	B747
	11000.	.1032	31.20	4890.	B747
	12000.	.1144	35.40	5380.	B747
	13000.	.1256	39.60	5870.	B747
	14000.	.1368	43.80	6360.	B747
	15000.	.1480	48.00	6850.	B747
	16000.	.1614	54.20	7410.	B747
	17000.	.1748	60.40	7970.	B747
	18000.	.1882	66.60	8530.	B747
	19000.	.2016	72.80	9090.	B747
	20000.	.2150	79.00	9650.	B747
DESCENT					
	0.	0.000	0.00	0.	B747
	1000.	.0086	2.20	34.	B747
	2000.	.0172	4.40	68.	B747
	3000.	.0258	6.60	102.	B747
	4000.	.0344	8.80	136.	B747
	5000.	.0430	11.00	170.	B747
	6000.	.0540	14.18	204.	B747
	7000.	.0650	17.36	238.	B747
	8000.	.0760	20.54	272.	B747
	9000.	.0870	23.72	306.	B747
	10000.	.0980	26.90	340.	B747
	11000.	.1308	37.80	446.	B747
	12000.	.1366	40.60	462.	B747
	13000.	.1424	43.40	478.	B747
	14000.	.1482	46.20	494.	B747
	15000.	.1540	49.00	510.	B747
	16000.	.1572	51.50	522.	B747
	17000.	.1604	54.00	534.	B747
	18000.	.1636	56.50	546.	B747
	19000.	.1668	59.00	558.	B747
	20000.	.1700	61.50	570.	B747

High Speed Climb/High Speed Descent

Distance - to - Climb/Descend Data

	ALTITUDE	TIME (Hours)	DISTANCE (nm)	FUEL (Pounds)	AIRCRAFT
CLIMB					
	0.	0.0000	0.00	0.	DC10
	1000.	.0056	1.50	220.	DC10
	2000.	.0112	3.00	440.	DC10
	3000.	.0168	4.50	660.	DC10
	4000.	.0224	6.00	880.	DC10
	5000.	.0280	7.50	1100.	DC10
	6000.	.0348	9.30	1326.	DC10
	7000.	.0416	11.10	1552.	DC10
	8000.	.0484	12.90	1778.	DC10
	9000.	.0552	14.70	2004.	DC10
	10000.	.0620	16.50	2230.	DC10
	11000.	.088[illegible]	26.20	308[illegible].	DC10
	12000.	.0966	29.40	3340.	DC10
	13000.	.1044	32.60	3600.	DC10
	14000.	.1122	35.80	3860.	DC10
	15000.	.1200	39.00	4120.	DC10
	16000.	.1308	43.70	4440.	DC10
	17000.	.1416	48.40	4760.	DC10
	18000.	.1524	53.10	5080.	DC10
	19000.	.1632	57.80	5400.	DC10
	20000.	.1740	62.50	5720.	DC10
DESCENT					
	0.	0.0000	0.00	0.	DC10
	1000.	.0132	2.50	81.	DC10
	2000.	.0264	5.00	162.	DC10
	3000.	.0396	7.50	244.	DC10
	4000.	.0528	10.00	325.	DC10
	5000.	.0660	12.50	406.	DC10
	6000.	.0782	15.82	466.	DC10
	7000.	.0904	19.14	526.	DC10
	8000.	.1026	22.46	586.	DC10
	9000.	.1148	25.78	646.	DC10
	10000.	.1270	29.10	706.	DC10
	11000.	.1590	40.44	848.	DC10
	12000.	.1650	42.88	876.	DC10
	13000.	.1710	45.32	905.	DC10
	14000.	.1770	47.76	933.	DC10
	15000.	.1830	50.20	961.	DC10
	16000.	.1850	52.74	982.	DC10
	17000.	.1930	55.28	1003.	DC10
	18000.	.1980	57.82	1024.	DC10
	19000.	.2030	60.36	1045.	DC10
	20000.	.2080	62.90	1066.	DC10

High Speed Climb/High Speed Descent

Distance - to - Climb/Descend Data

	ALTITUDE	TIME (Hours)	DISTANCE (nm)	FUEL (Pounds)	AIRCRAFT
CLIMB					
	0.	0.0000	0.00	0.	F.28
	1000.	.0047	1.14	45.	F.28
	2000.	.0093	2.28	90.	F.28
	3000.	.0140	3.42	135.	F.28
	4000.	.0186	4.56	180.	F.28
	5000.	.0233	5.70	225.	F.28
	6000.	.0280	7.04	268.	F.28
	7000.	.0327	8.38	311.	F.28
	8000.	.0373	9.72	354.	F.28
	9000.	.0420	11.06	397.	F.28
	10000.	.0467	12.40	440.	F.28
	11000.	.0520	14.08	486.	F.28
	12000.	.0573	15.76	532.	F.28
	13000.	.0627	17.44	578.	F.28
	14000.	.0680	19.12	624.	F.28
	15000.	.0733	20.80	670.	F.28
	16000.	.0800	23.20	720.	F.28
	17000.	.0867	25.60	770.	F.28
	18000.	.0933	28.00	820.	F.28
	19000.	.1000	30.40	870.	F.28
	20000.	.1067	32.80	920.	F.28
DESCENT					
	0.	0.0000	0.00	0.	F.28
	1000.	.0090	2.00	19.	F.28
	2000.	.0180	4.00	38.	F.28
	3000.	.0270	6.00	57.	F.28
	4000.	.0360	8.00	76.	F.28
	5000.	.0450	10.00	95.	F.28
	6000.	.0543	12.60	113.	F.28
	7000.	.0637	15.20	131.	F.28
	8000.	.0730	17.80	149.	F.28
	9000.	.0824	20.40	167.	F.28
	10000.	.0917	23.00	185.	F.28
	11000.	.1010	26.60	215.	F.28
	12000.	.1103	30.20	247.	F.28
	13000.	.1197	33.80	278.	F.28
	14000.	.1290	37.40	309.	F.28
	15000.	.1383	41.00	340.	F.28
	16000.	.1476	44.80	370.	F.28
	17000.	.1570	48.60	400.	F.28
	18000.	.1663	52.40	430.	F.28
	19000.	.1757	56.20	460.	F.28
	20000.	.1850	60.00	490.	F.28

High Speed Climb/High Speed Descent

Distance - to - Climb/Descend Data

	ALTITUDE	TIME (Hours)	DISTANCE (nm)	FUEL (Pounds)	AIRCRAFT
CLIMB					
	0.	0.0000	0.00	0.	LEAR
	1000.	.0033	1.20	16.	LEAR
	2000.	.0067	2.40	32.	LEAR
	3000.	.0100	3.60	48.	LEAR
	4000.	.0134	4.80	64.	LEAR
	5000.	.0167	6.00	80.	LEAR
	6000.	.0197	6.80	94.	LEAR
	7000.	.0227	7.60	108.	LEAR
	8000.	.0257	8.40	122.	LEAR
	9000.	.0287	9.20	136.	LEAR
	10000.	.0317	10.00	150.	LEAR
	11000.	.0360	11.71	165.	LEAR
	12000.	.0404	13.42	181.	LEAR
	13000.	.0447	15.13	197.	LEAR
	14000.	.0490	16.84	212.	LEAR
	15000.	.0534	18.55	228.	LEAR
	16000.	.0577	20.26	243.	LEAR
	17000.	.0620	21.97	259.	LEAR
	18000.	.0663	23.68	274.	LEAR
	19000.	.0707	25.39	290.	LEAR
	20000.	.0750	27.10	305.	LEAR
DESCENT					
	0.	0.0000	0.00	0.	LEAR
	1000.	.0073	2.40	11.	LEAR
	2000.	.0147	4.80	22.	LEAR
	3000.	.0220	7.20	33.	LEAR
	4000.	.0294	9.60	44.	LEAR
	5000.	.0367	12.00	55.	LEAR
	6000.	.0440	14.40	65.	LEAR
	7000.	.0513	16.80	76.	LEAR
	8000.	.0587	19.20	86.	LEAR
	9000.	.0660	21.60	97.	LEAR
	10000.	.0733	24.00	107.	LEAR
	11000.	.0806	26.81	116.	LEAR
	12000.	.0880	29.62	125.	LEAR
	13000.	.0953	32.43	134.	LEAR
	14000.	.1027	35.24	143.	LEAR
	15000.	.1100	38.05	153.	LEAR
	16000.	.1173	40.86	162.	LEAR
	17000.	.1247	43.67	171.	LEAR
	18000.	.1320	46.48	180.	LEAR
	19000.	.1394	49.29	189.	LEAR
	20000.	.1467	52.10	198.	LEAR

High Speed Climb/High Speed Descent

Distance - to - Climb/Descend Data

	ALTITUDE	TIME (Hours)	DISTANCE (nm)	FUEL (Pounds)	AIRCRAFT
CLIMB					
	0.	0.000	0.0	0.	F227
	1000.	.0115	1.83	28.	F227
	2000.	.0230	3.65	56.	F227
	3000.	.0344	5.48	84.	F227
	4000.	.0459	7.30	112.	F227
	5000.	.0594	9.43	139.	F227
	6000.	.0730	11.55	165.	F227
	7000.	.0865	13.68	192.	F227
	8000.	.10[illegible]	15.80	218.	F227
	9000.	.1154	18.35	248.	F227
	10000.	.1309	20.90	279.	F227
	11000.	.1463	23.45	309.	F227
	12000.	.1617	26.00	339.	F227
	13000.	.1809	29.50	374.	F227
	14000.	.20[illegible]	33.00	410.	F227
	15000.	.2192	36.50	445.	F227
	16000.	.2385	40.00	480.	F227
	17000.	.2646	44.80	524.	F227
	18000.	.2908	49.60	569.	F227
	19000.	.3171	54.40	613.	F227
	20000.	.34[illegible]	59.20	657.	F227
DESCENT					
	0.	0.0000	0.00	0.	F227
	1000.	.0067	1.90	12.	F227
	2000.	.0133	3.80	24.	F227
	3000.	.0200	5.70	36.	F227
	4000.	.0266	7.60	48.	F227
	5000.	.0333	9.50	60.	F227
	6000.	.0416	11.90	74.	F227
	7000.	.0500	14.30	88.	F227
	8000.	.0583	16.70	102.	F227
	9000.	.0667	19.10	116.	F227
	10000.	.0750	21.50	130.	F227
	11000.	.0830	23.84	143.	F227
	12000.	.0910	26.18	156.	F227
	13000.	.0990	28.52	168.	F227
	14000.	.1071	30.86	181.	F227
	15000.	.1150	33.20	194.	F227
	16000.	.1233	35.76	205.	F227
	17000.	.1317	38.32	216.	F227
	18000.	.1400	40.88	228.	F227
	19000.	.1484	43.44	239.	F227
	20000.	.1567	46.00	250.	F227

High Speed Climb/High Speed Descent

Altitude Restriction Penalty Data

	ALTITUDE	Δ-TIME (Hours)	Δ-FUEL (Pounds)	AIRCRAFT
CLIMB				
	0.	.001826	10.529	DC-9
	1000.	.001772	9.947	DC-9
	2000.	.001718	9.364	DC-9
	3000.	.001665	8.782	DC-9
	4000.	.001611	8.199	DC-9
	5000.	.001557	7.617	DC-9
	6000.	.001503	7.118	DC-9
	7000.	.001449	6.619	DC-9
	8000.	.001394	6.120	DC-9
	9000.	.001340	5.621	DC-9
	10000.	.001286	5.122	DC-9
	11000.	.000285	5.344	DC-9
	12000.	.000250	4.976	DC-9
	13000.	.000216	4.609	DC-9
	14000.	.000181	4.241	DC-9
	15000.	.000146	3.873	DC-9
	16000.	.000114	3.589	DC-9
	17000.	.000082	3.305	DC-9
	18000.	.000050	3.022	DC-9
	19000.	.000018	2.738	DC-9
	20000.	-.000014	2.454	DC-9
DESCENT				
	0.	.001748	11.708	DC-9
	1000.	.001694	11.158	DC-9
	2000.	.001640	10.608	DC-9
	3000.	.001587	10.057	DC-9
	4000.	.001533	9.507	DC-9
	5000.	.001479	8.957	DC-9
	6000.	.001425	8.481	DC-9
	7000.	.001371	8.005	DC-9
	8000.	.001316	7.528	DC-9
	9000.	.001262	7.052	DC-9
	10000.	.001208	6.576	DC-9
	11000.	.000207	8.090	DC-9
	12000.	.000172	7.657	DC-9
	13000.	.000138	7.225	DC-9
	14000.	.000103	6.792	DC-9
	15000.	.000068	6.359	DC-9
	16000.	.000036	6.068	DC-9
	17000.	.000004	5.777	DC-9
	18000.	-.000028	5.485	DC-9
	19000.	-.000060	5.194	DC-9
	20000.	-.000092	4.903	DC-9

High Speed Climb/High Speed Descent

Altitude Restriction Penalty Data

	ALTITUDE	Δ-TIME (Hours)	Δ-FUEL (Pounds)	AIRCRAFT
CLIMB				
	0.	.001908	15.795	B727
	1000.	.001854	14.971	B727
	2000.	.0018[illegible]	14.147	B727
	3000.	.001747	13.32[illegible]	B727
	4000.	.001693	12.49[illegible]	B727
	5000.	.001639	11.675	B727
	6000.	.00158[illegible]	10.965	B727
	7000.	.001531	10.255	B727
	8000.	.001476	9.545	B727
	9000.	.001422	8.836	B727
	10000.	.001368	8.126	B727
	11000.	.00[illegible]73	8.997	B727
	12000.	.00[illegible]4	8.575	B727
	13000.	.00[illegible]7	8.152	B727
	14000.	-.00[illegible]27	7.730	B727
	15000.	-.00[illegible]69	7.307	B727
	16000.	-.00[illegible]59	6.[illegible]53	B727
	17000.	-.00[illegible]58	5.99[illegible]	B727
	18000.	-.00[illegible]57	5.346	B727
	19000.	-.00[illegible]56	4.692	B727
	20000.	-.00[illegible]55	4.038	B727
DESCENT				
	0.	.001831	16.536	B727
	1000.	.001777	15.742	B727
	2000.	.001723	14.9[illegible]8	B727
	3000.	.001670	14.[illegible]54	B727
	4000.	.0016[illegible]	13.360	B727
	5000.	.001562	12.56[illegible]	B727
	6000.	.0015[illegible]8	11.873	B727
	7000.	.001454	11.180	B727
	8000.	.00139[illegible]	10.487	B727
	9000.	.001345	9.794	B727
	10000.	.00129[illegible]	9.101	B727
	11000.	-.00[illegible]4	11.451	B727
	12000.	-.00[illegible]37	11.008	B727
	13000.	-.00[illegible]71	10.564	B727
	14000.	-.0001[illegible]4	10.121	B727
	15000.	-.000137	9.677	B727
	16000.	-.000136	8.9[illegible]7	B727
	17000.	-.000135	8.318	B727
	18000.	-.000135	7.638	B727
	19000.	-.000134	6.959	B727
	20000.	-.00013[illegible]	6.279	B727

High Speed Climb/High Speed Descent

Altitude Restriction Penalty Data

	ALTITUDE	Δ-TIME (Hours)	Δ-FUEL (Pounds)	AIRCRAFT
CLIMB				
	0.	.001868	27.084	DC-8
	1000.	.001814	27.117	DC-8
	2000.	.001760	27.151	DC-8
	3000.	.001707	27.184	DC-8
	4000.	.001653	27.218	DC-8
	5000.	.001599	27.251	DC-8
	6000.	.001545	24.983	DC-8
	7000.	.001491	22.715	DC-8
	8000.	.001436	20.446	DC-8
	9000.	.001382	18.178	DC-8
	10000.	.001328	15.910	DC-8
	11000.	.000304	13.671	DC-8
	12000.	.000262	12.799	DC-8
	13000.	.000220	11.927	DC-8
	14000.	.000177	11.054	DC-8
	15000.	.000135	10.182	DC-8
	16000.	.000093	9.664	DC-8
	17000.	.000051	9.146	DC-8
	18000.	.000009	8.629	DC-8
	19000.	-.000033	8.111	DC-8
	20000.	-.000075	7.593	DC-8
DESCENT				
	0.	.001819	27.489	DC-8
	1000.	.001765	26.274	DC-8
	2000.	.001711	25.060	DC-8
	3000.	.001658	23.845	DC-8
	4000.	.001604	22.631	DC-8
	5000.	.001550	21.416	DC-8
	6000.	.001496	20.471	DC-8
	7000.	.001442	19.526	DC-8
	8000.	.001387	18.582	DC-8
	9000.	.001333	17.637	DC-8
	10000.	.001279	16.692	DC-8
	11000.	.000255	18.830	DC-8
	12000.	.000213	18.054	DC-8
	13000.	.000171	17.277	DC-8
	14000.	.000129	16.501	DC-8
	15000.	.000087	15.724	DC-8
	16000.	.000045	15.182	DC-8
	17000.	.000003	14.639	DC-8
	18000.	-.000039	14.097	DC-8
	19000.	-.000081	13.554	DC-8
	20000.	-.000123	13.012	DC-8

High Speed Climb/High Speed Descent

Altitude Restriction Penalty Data

	ALTITUDE	Δ-TIME (Hours)	Δ-FUEL (Pounds)	AIRCRAFT
CLIMB				
	0.	.001972	62.416	B747
	1000.	.001918	59.782	B747
	2000.	.001864	57.148	B747
	3000.	.001810	54.514	B747
	4000.	.001757	51.880	B747
	5000.	.001703	49.246	B747
	6000.	.001649	46.984	B747
	7000.	.001595	44.72[illegible]	B747
	8000.	.001540	42.460	B747
	9000.	.001486	40.198	B747
	10000.	.001432	37.936	B747
	11000.	.001227	21.164	B747
	12000.	.001194	20.162	B747
	13000.	.001161	19.160	B747
	14000.	.001128	18.158	B747
	15000.	.001095	17.156	B747
	16000.	.000060	16.758	B747
	17000.	.000025	16.360	B747
	18000.	-.000[illegible]9	15.962	B747
	19000.	-.000044	15.564	B747
	20000.	-.000079	15.166	B747
DESCENT				
	0.	.001925	42.390	B747
	1000.	.001871	40.336	B747
	2000.	.001818	38.282	B747
	3000.	.001764	36.228	B747
	4000.	.001711	34.174	B747
	5000.	.001657	32.120	B747
	6000.	.001603	30.[illegible]5	B747
	7000.	.001549	28.550	B747
	8000.	.001494	26.764	B747
	9000.	.001440	24.979	B747
	10000.	.001386	23.194	B747
	11000.	.001181	26.741	B747
	12000.	.001148	25.757	B747
	13000.	.001115	24.772	B747
	14000.	.001081	23.788	B747
	15000.	.001048	22.803	B747
	16000.	.001013	22.524	B747
	17000.	-.000021	22.245	B747
	18000.	-.000056	21.967	B747
	19000.	-.000090	21.688	B747
	20000.	-.000125	21.409	B747

High Speed Climb/High Speed Descent

Altitude Restriction Penalty Data

	ALTITUDE	Δ-TIME (Hours)	Δ-FUEL (Pounds)	AIRCRAFT
CLIMB				
	0.	.001934	27.306	DC10
	1000.	.001880	26.156	DC10
	2000.	.001826	25.006	DC10
	3000.	.001773	23.856	DC10
	4000.	.001719	22.706	DC10
	5000.	.001665	21.556	DC10
	6000.	.001611	20.490	DC10
	7000.	.001557	19.424	DC10
	8000.	.001502	18.358	DC10
	9000.	.001448	17.292	DC10
	10000.	.001394	16.226	DC10
	11000.	.000463	13.630	DC10
	12000.	.000427	12.846	DC10
	13000.	.000392	12.063	DC10
	14000.	.000356	11.279	DC10
	15000.	.000321	10.496	DC10
	16000.	.000288	9.826	DC10
	17000.	.000255	9.157	DC10
	18000.	.000222	8.437	DC10
	19000.	.000189	7.818	DC10
	20000.	.000156	7.148	DC10
DESCENT				
	0.	.001895	25.858	DC10
	1000.	.001841	24.841	DC10
	2000.	.001787	23.825	DC10
	3000.	.001734	22.806	DC10
	4000.	.001680	21.788	DC10
	5000.	.001626	20.771	DC10
	6000.	.001572	19.847	DC10
	7000.	.001518	18.924	DC10
	8000.	.001463	18.001	DC10
	9000.	.001409	17.077	DC10
	10000.	.001355	16.153	DC10
	11000.	.000423	17.094	DC10
	12000.	.000388	16.382	DC10
	13000.	.000352	15.669	DC10
	14000.	.000317	14.957	DC10
	15000.	.000281	14.245	DC10
	16000.	.000248	13.635	DC10
	17000.	.000215	13.024	DC10
	18000.	.000183	12.414	DC10
	19000.	.000150	11.803	DC10
	20000.	.000117	11.193	DC10

High Speed Climb/High Speed Descent

Altitude Restriction Penalty Data

	ALTITUDE	Δ-TIME (Hours)	Δ-FUEL (Pounds)	AIRCRAFT
CLIMB				
	0.	.001630	7.391	F.28
	1000.	.001576	6.854	F.28
	2000.	.001523	6.317	F.28
	3000.	.001469	5.780	F.28
	4000.	.001416	5.243	F.28
	5000.	.001362	4.706	F.28
	6000.	.001308	4.396	F.28
	7000.	.001254	4.087	F.28
	8000.	.001199	3.777	F.28
	9000.	.001145	3.468	F.28
	10000.	.001091	3.158	F.28
	11000.	.000311	3.566	F.28
	12000.	.000274	3.3[illegible]9	F.28
	13000.	.000236	3.112	F.28
	14000.	.000199	2.835	F.28
	15000.	.000162	2.658	F.28
	16000.	.000126	2.551	F.28
	17000.	.000[illegible]9	2.4[illegible]3	F.28
	18000.	.000055	2.3[illegible]6	F.28
	19000.	.000019	2.228	F.28
	20000.	-.000017	2.121	F.28
DESCENT				
	0.	.001608	8.627	F.28
	1000.	.001554	8.115	F.28
	2000.	.0015[illegible]	7.602	F.28
	3000.	.001447	7.090	F.28
	4000.	.001393	6.577	F.28
	5000.	.001339	6.065	F.28
	6000.	.001285	5.678	F.28
	7000.	.001231	5.291	F.28
	8000.	.001176	4.905	F.28
	9000.	.001122	4.518	F.28
	10000.	.001068	4.131	F.28
	11000.	.000288	5.357	F.28
	12000.	.000251	5.103	F.28
	13000.	.000213	4.850	F.28
	14000.	.000176	4.596	F.28
	15000.	.000139	4.342	F.28
	16000.	.000103	4.194	F.28
	17000.	.000068	4.046	F.28
	18000.	.000032	3.898	F.28
	19000*.	-.000003	3.750	F.28
	20000.	-.000039	3.602	F.28

High Speed Climb/High Speed Descent

Altitude Restriction Penalty Data

	ALTITUDE	Δ-TIME (Hours)	Δ-FUEL (Pounds)	AIRCRAFT
CLIMB				
	0.	.001696	3.832	LEAR
	1000.	.001642	3.598	LEAR
	2000.	.001588	3.364	LEAR
	3000.	.001535	3.129	LEAR
	4000.	.001481	2.895	LEAR
	5000.	.001427	2.661	LEAR
	6000.	.001373	2.526	LEAR
	7000.	.001319	2.392	LEAR
	8000.	.001264	2.257	LEAR
	9000.	.001210	2.123	LEAR
	10000.	.001156	1.988	LEAR
	11000.	.000376	2.164	LEAR
	12000.	.000339	2.066	LEAR
	13000.	.000301	1.967	LEAR
	14000.	.000264	1.869	LEAR
	15000.	.000227	1.771	LEAR
	16000.	.000191	1.724	LEAR
	17000.	.000156	1.677	LEAR
	18000.	.000120	1.630	LEAR
	19000.	.000085	1.583	LEAR
	20000.	.000049	1.536	LEAR
DESCENT				
	0.	.001696	3.962	LEAR
	1000.	.001642	3.738	LEAR
	2000.	.001588	3.513	LEAR
	3000.	.001535	3.289	LEAR
	4000.	.001481	3.064	LEAR
	5000.	.001427	2.840	LEAR
	6000.	.001373	2.673	LEAR
	7000.	.001319	2.506	LEAR
	8000.	.001264	2.339	LEAR
	9000.	.001210	2.172	LEAR
	10000.	.001156	2.005	LEAR
	11000.	.000376	2.539	LEAR
	12000.	.000339	2.428	LEAR
	13000.	.000301	2.317	LEAR
	14000.	.000264	2.206	LEAR
	15000.	.000227	2.095	LEAR
	16000.	.000191	2.031	LEAR
	17000.	.000156	1.967	LEAR
	18000.	.000120	1.903	LEAR
	19000.	.000085	1.839	LEAR
	20000.	.000049	1.775	LEAR

High Speed Climb/High Speed Descent

Altitude Restriction Penalty Data

	ALTITUDE	Δ-TIME (Hours)	Δ-FUEL (Pounds)	AIRCRAFT
CLIMB				
	0.	.000086	3.187	F227
	1000.	.000085	3.168	F227
	2000.	.000084	3.149	F227
	3000.	.000084	3.130	F227
	4000.	.000083	3.111	F227
	5000.	.000082	3.093	F227
	6000.	.000081	3.074	F227
	7000.	.000081	3.055	F227
	8000.	.000080	3.036	F227
	9000.	.000079	3.017	F227
	10000.	.000078	2.998	F227
	11000.	.000077	2.979	F227
	12000.	.000077	2.960	F227
	13000.	.000076	2.941	F227
	14000.	.000075	2.922	F227
	15000.	.000074	2.904	F227
	16000.	.000074	2.885	F227
	17000.	.000073	2.866	F227
	18000.	.000072	2.847	F227
	19000.	.000071	2.828	F227
	20000.	.000070	2.809	F227
DESCENT				
	0.	.000165	4.118	F227
	1000.	.000156	3.944	F227
	2000.	.000146	3.771	F227
	3000.	.000137	3.597	F227
	4000.	.000127	3.424	F227
	5000.	.000118	3.250	F227
	6000.	.000106	3.005	F227
	7000.	.000094	2.759	F227
	8000.	.000082	2.514	F227
	9000.	.000070	2.268	F227
	10000.	.000058	2.023	F227
	11000.	.000049	1.807	F227
	12000.	.000040	1.591	F227
	13000.	.000032	1.376	F227
	14000.	.000023	1.160	F227
	15000.	.000014	.944	F227
	16000.	.000011	.755	F227
	17000.	.000008	.566	F227
	18000.	.000006	.378	F227
	19000.	.000003	.189	F227
	20000.	0.000000	0.0	F227

Long Range Descent

Distance - to - Descend Data

	ALTITUDE	TIME (Hours)	DISTANCE (nm)	FUEL (Pounds)	AIRCRAFT
DESCENT					
	0.	0.0000	0.00	0.	DC-9
	1000.	.0096	2.50	18.	DC-9
	2000.	.0192	5.00	36.	DC-9
	3000.	.0288	7.50	54.	DC-9
	4000.	.0384	10.00	72.	DC-9
	5000.	.0480	12.50	90.	DC-9
	6000.	.0572	15.04	104.	DC-9
	7000.	.0664	17.58	118.	DC-9
	8000.	.0756	20.12	132.	DC-9
	9000.	.0848	22.66	146.	DC-9
	10000.	.0940	25.20	160.	DC-9
	11000.	.1028	27.80	171.	DC-9
	12000.	.1116	30.40	182.	DC-9
	13000.	.1204	33.00	194.	DC-9
	14000.	.1292	35.60	205.	DC-9
	15000.	.1380	38.20	216.	DC-9
	16000.	.1460	40.84	224.	DC-9
	17000.	.1540	43.48	232.	DC-9
	18000.	.1620	46.12	239.	DC-9
	19000.	.1700	48.76	247.	DC-9
	20000.	.1780	51.40	255.	DC-9

DESCENT					
	0.	0.0000	0.00	0.	B727
	1000.	.0108	2.50	30.	B727
	2000.	.0216	5.00	60.	B727
	3000.	.0324	7.50	91.	B727
	4000.	.0432	10.00	121.	B727
	5000.	.0540	12.50	151.	B727
	6000.	.0644	15.38	175.	B727
	7000.	.0748	18.26	199.	B727
	8000.	.0852	21.14	222.	B727
	9000.	.0956	24.02	246.	B727
	10000.	.1060	26.90	270.	B727
	11000.	.1156	29.84	288.	B727
	12000.	.1252	32.78	306.	B727
	13000.	.1348	35.72	324.	B727
	14000.	.1444	38.66	342.	B727
	15000.	.1540	41.60	360.	B727
	16000.	.1616	44.46	374.	B727
	17000.	.1692	47.32	387.	B727
	18000.	.1768	50.18	401.	B727
	19000.	.1844	53.04	414.	B727
	20000.	.1920	55.90	428.	B727

Long Range Descent

Distance - to - Descend Data

	ALTITUDE	TIME (Hours)	DISTANCE (nm)	FUEL (Pounds)	AIRCRAFT
DESCENT					
	0.	0.0	0.0	0.	DC-8
	1000.	.0130	2.50	59.	DC-8
	2000.	.0260	5.00	118.	DC-8
	3000.	.0390	7.50	176.	DC-8
	4000.	.0520	10.00	235.	DC-8
	5000.	.0650	12.50	294.	DC-8
	6000.	.0766	15.72	340.	DC-8
	7000.	.0882	18.94	385.	DC-8
	8000.	.0998	22.16	431.	DC-8
	9000.	.1114	25.38	476.	DC-8
	10000.	.1230	28.60	522.	DC-8
	11000.	.1338	31.88	560.	DC-8
	12000.	.1446	35.16	598.	DC-8
	13000.	.1554	38.44	635.	DC-8
	14000.	.1662	41.72	673.	DC-8
	15000.	.1770	45.00	711.	DC-8
	16000.	.1880	48.50	746.	DC-8
	17000.	.1990	52.00	781.	DC-8
	18000.	.210*	55.50	815.	DC-8
	19000.	.2210	59.00	850.	DC-8
	20000.	.2320	62.50	885.	DC-8
DESCENT					
	0.	0.0000	0.00	0.	DC10
	1000.	.0140	2.50	82.	DC10
	2000.	.0280	5.00	163.	DC10
	3000.	.0420	7.50	245.	DC10
	4000.	.0560	10.00	326.	DC10
	5000.	.0700	12.50	408.	DC10
	6000.	.0816	15.90	467.	DC10
	7000.	.0932	19.30	526.	DC10
	8000.	.1048	22.70	584.	DC10
	9000.	.1164	26.10	643.	DC10
	10000.	.1280	29.50	702.	DC10
	11000.	.1390	32.86	749.	DC10
	12000.	.1500	36.22	796.	DC10
	13000.	.1610	39.58	842.	DC10
	14000.	.1720	42.94	889.	DC10
	15000.	.1830	46.30	936.	DC10
	16000.	.1928	49.36	972.	DC10
	17000.	.2026	52.42	1008.	DC10
	18000.	.2124	55.48	1043.	DC10
	19000.	.2222	58.54	1079.	DC10
	20000.	.2320	61.60	1115.	DC10

Long Range Descent

Altitude Restriction Penalty Data

	ALTITUDE	Δ-TIME (Hours)	Δ-FUEL (Pounds)	AIRCRAFT
DESCENT				
	0.	.001630	11.323	DC-9
	1000.	.001576	10.770	DC-9
	2000.	.001523	10.218	DC-9
	3000.	.001469	9.665	DC-9
	4000.	.001416	9.113	DC-9
	5000.	.001362	8.560	DC-9
	6000.	.001308	8.076	DC-9
	7000.	.001254	7.591	DC-9
	8000.	.001199	7.107	DC-9
	9000.	.001145	6.622	DC-9
	10000.	.001091	6.138	DC-9
	11000.	.001042	5.723	DC-9
	12000.	.000993	5.308	DC-9
	13000.	.000944	4.894	DC-9
	14000.	.000895	4.479	DC-9
	15000.	.000846	4.064	DC-9
	16000.	.000798	3.736	DC-9
	17000.	.000750	3.408	DC-9
	18000.	.000703	3.081	DC-9
	19000.	.000655	2.753	DC-9
	20000.	.000617	2.425	DC-9
DESCENT				
	0.	.001775	19.658	B727
	1000.	.001721	18.773	B727
	2000.	.001668	17.8[illegible]	B727
	3000.	.001614	17.003	B727
	4000.	.001561	16.118	B727
	5000.	.001507	15.233	B727
	6000.	.001453	14.510	B727
	7000.	.001399	13.788	B727
	8000.	.001344	13.065	B727
	9000.	.001290	12.343	B727
	10000.	.001236	11.620	B727
	11000.	.001187	10.935	B727
	12000.	.001138	10.251	B727
	13000.	.001089	9.566	B727
	14000.	.001040	8.382	B727
	15000.	.000991	8.197	B727
	16000.	.000940	7.662	B727
	17000.	.00088[illegible]	7.126	B727
	18000.	.000837	6.591	B727
	19000.	.000785	6.055	B727
	20000.	.000734	5.520	B727

Long Range Descent

Altitude Restriction Penalty Data

DESCENT

ALTITUDE	Δ-TIME (Hours)	Δ-FUEL (Pounds)	AIRCRAFT
0.	.001763	27.778	DC-8
1000.	.001709	26.550	DC-8
2000.	.001655	25.322	DC-8
3000.	.001602	24.093	DC-8
4000.	.001548	22.865	DC-8
5000.	.001494	21.637	DC-8
6000.	.001440	20.678	DC-8
7000.	.001386	19.718	DC-8
8000.	.001331	18.759	DC-8
9000.	.001277	17.799	DC-8
10000.	.001223	16.840	DC-8
11000.	.001174	15.972	DC-8
12000.	.001125	15.104	DC-8
13000.	.001076	14.236	DC-8
14000.	.001027	13.368	DC-8
15000.	.000978	12.500	DC-8
16000.	.000927	11.728	DC-8
17000.	.000875	10.957	DC-8
18000.	.000824	10.185	DC-8
19000.	.000772	9.414	DC-8
20000.	.000721	8.642	DC-8

DESCENT

ALTITUDE	Δ-TIME (Hours)	Δ-FUEL (Pounds)	AIRCRAFT
0.	.001817	26.647	DC10
1000.	.001763	25.630	DC10
2000.	.001709	24.612	DC10
3000.	.001656	23.595	DC10
4000.	.001602	22.577	DC10
5000.	.001548	21.560	DC10
6000.	.001494	20.636	DC10
7000.	.001440	19.713	DC10
8000.	.001385	18.789	DC10
9000.	.001331	17.866	DC10
10000.	.001277	16.942	DC10
11000.	.001228	16.144	DC10
12000.	.001179	15.345	DC10
13000.	.001130	14.547	DC10
14000.	.001081	13.748	DC10
15000.	.001032	12.950	DC10
16000.	.000984	12.200	DC10
17000.	.000936	11.450	DC10
18000.	.000889	10.700	DC10
19000.	.000841	9.950	DC10
20000.	.000793	9.200	DC10

APPENDIX B

UNITED AIR LINES FLIGHT PLANNING PROGRAM

OUTPUT FORMAT AND KEY

ALTERNATE WEATHER ROUTE STUDY

EXAMPLE OUTPUT

```
SCIOD
ACHDQCOUA C30849 1262 041
LT 51X      03            LAX WAS      3013
        DISTANCE                    DISTANCE
ROUTE   WIND   GROUND      ROUTE   WIND   GROUND
15C     1772   2014        07C     1808   2047
16C     1777   2016        08C     1821   2061
13C     1779   2014        18C     1823   2086
02C     1784   2014        04C     1827   2076
17C     1787   2034        05C     1838   2084
10C     1788   2016        09C     1860   2124
14C     1788   2023        19C     1866   2125
11C     1799   2024        03C     1871   2147
12C     1799   2027        20C     1873   2141
06C     1806   2042        01C     1882   2161

03:56/00:01  54180 150          100•XXX                     RT:15 (P)

D00 2014NM 3370/3911 2829/3370 CLB 00 C50  2579              791 LAX

RCA      203 37 830 -01 473 24109 106 579 27 108             683

167      365 37 830 -05 468 24070 070 544 39  87             596

168      250 37 830 -05 469 25067 066 535 28  61             535

580      638 37 830 -02 472 28090 090 562 71 152             303

182      271 37 830 -01 473 30087 071 544 30  62             321

POD      187 37 830  04 479 32084 039 518 21  45             276

-WAS     100                34064-031        20  26          250

33  3414 03:55  565 3094    M83

29  3484 03:54  655 3094    M83

27  3526 03:55  697 3094    M83

25  3569 03:54  740 3094    M83

    DA51X H/DC10/A C473 LAX P1200 370

    FAA/DIRECT LAX IAD 15

    SCI RT 397
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UNITED

Flight Plan Forecast

71. FLIGHT PLAN FORECASTS are provided from an Automatic Flight Planning and Monitoring computer system (AFPAM). The following message format is a typical Flight Plan Forecast for an advance section of Flight 29 from JFK to SFO.

NOTE: The Captain and Dispatcher are responsible for validating all flight plans including Flight Plan Forecasts and for assuring they select the same forecast.

1) IADDD JFKDD

	a	b	c	d	e	f	g	h	i	j	k
2)	8009	(A29)	-20	8012	AFCH	IAD1	ORD7	SFO5	PDS:OAK	IAD1	SPFI

	a	b	c	d	e	f	g	h	i	j
3)	05:23	/05:18	11318O	230	152	48	OAK SJC	20FY	RT: 5	(P)

	a	b	c	d	e	f	g	h	i	j	k	l
4)	500	2307NM	5368/	6771	4237/	5640	CLB 12	-015	3787	1561/	1581	JFK

	a	b	c	d	e	f	g	h	i	j	k	l
5)	RCA	151	35	84	09	495	30058	-057	438	29	184	1397
	PSB	46	35	84	09	495	29064	-064	431	7	23	1374
	JOT	469	35	84	10	496	27048	-048	448	64	234	1140
	RCA	53	39	84	04	486		-048	438	7	30	1110
	-LNK	334	39	84	04	486	23041	-034	452	45	140	964
	DEN	373	39	84	03	485	21029	-020	465	43	155	609
	MLF	397	39	84	04	486	28047	-045	441	53	162	647
	POD	322	39	84	02	484	27082	-081	403	48	145	502

			a			
6)	-SFO	122	25021-021	22	52	450

	a	b	c	d	e	f
7)	39	5363	05:24	1126	000	M84
	35	5415	05:21	1178	1733	M84
	31	5507	05:12	1270	1200	M84
	28	5601	05:05	1364	1252	M84
	26	5672	04:59	1435	1236	M84
	24	5753	04:55	1516	1344	M84

	a	b	c	d	e	f
8)	UA8009	H/B747/F	495	JFK	P2200	350

g: JFK..RBV.J80.DEN.J80.OAL..SFO(PREFERRED)

9) HONKER... LITE CAT VCNTY OF CONTL DIVIDE

UNITED

1) Address of message.

2) a. Radio Communications number
   b. Published flight number. Omitted if both radio and published number are identical.
   c. Flight date
   d. Plane number
   e. Selcal code
   f. Dispatch Sector controlling departure station
   g. ORDDD Sector controlling enroute portion of flight while traversing ORDDD area. Appears only in long range flight plans not originating or terminating in ORDDD area.
   h. Dispatch Sector controlling arrival station
   i. Preferred Diversion Station(s) Will appear when Planning Alert Message in effect for arrival station.
   j. Releasing Dispatch Sector
   k. Flight Plan Forecast number.

3) a. Planned flight time
   b. Scheduled target time
   c. Planned total burnout - 113,100 lbs.
   d. Combined FAA reserve and contingency fuel - 23,000 lbs.
   e. Holding/detouring fuel - 15,200 lbs.
   f. Alternate/diversion fuel - 4,800 lbs. If PDS (line 2) has not been assigned to the flight, this is the computer-generated fuel required for the most distant alternate. If PDS has been assigned, this is the computer-generated fuel required for the diversion station(s) or the required alternate(s) whichever is farther. "★" indicates the figure was entered manually and not computer-generated.
   g. Alternates OAK, SJC. If no alternate, "NA". If a fuel value appears in "f" and "NA" in "g", this is a reduced mach flight plan. The fuel value is the difference between standard mach burnout and reduced mach burnout and is added to the total fuel.
   h. Amount of fuel, if any, being ferried for the next flight.
   i. Computer-stored route number
   j. (P) indicates plan computed in accordance with Company fuel policy; omitted if not. "5PD" in this space indicates a B747 fifth-pod plan. → "YDI" indicates B-727 yaw-damper-inop. plan.

4) a. Pounds of fuel/min. gained over Base Plan. If blank, this is a reduced mach flight plan with burnout less than the Base Plan. "000" indicates this is the Base Plan.
   b. Total route mileage - 2307 nautical miles.
   c. Planned takeoff gross weight - 536,800 lbs.
   d. Operationally allowable takeoff gross weight - 677,100 lbs. This is the least of:
      1) Max structural T/O gross weight, or
      2) Max allowable landing weight plus burnout, or
      3) Max. allowable T/O weight (performance or runway limited) as determined by conditions expected to prevail at time of T/O, i.e. runway, wind, temp., etc. This is entered by Dispatch when they expect allowable T/O weight will be less than 1) or 2) above. When it is put in, the basis for its derivation, i.e. wind, runway, temp., flap setting, etc. is noted in the remarks section.

NOTE: Actual allowable T/O weight must be checked just prior to T/O - Page 118, para. 16.

   e. Planned landing weight - 423,700 lbs.

f. Maximum allowable landing gross weight which was entered in the FPF request - 564,000 lbs.

g. Deviation from standard temperature used in computing climb performance - 12° above standard.

h. Headwind (indicated by "-") or tailwind component used in computing climb performance - 15 knots headwind.

i. Zero fuel weight - 378,700 lbs.

j. Fuel required for release - 156,100 lbs. If no fuel is being ferried, the fuel required for release is the figure in the next column(k).

k. Total fuel to be carried if load and operating conditions permit. This will be the fuel required for release if no fuel is being ferried. This is the fuel weight used in the computation of the flight plan.

l. Departure station at which fuel in k. is boarded.

5) a. Flight plan check points. Reporting point when preceded by a minus sign "-". An "R" suffix indicates an overwater reclear point.

b. Segment mileage in nautical miles.

c. Flight level in thousands of feet at check point. AFPAM produces optimum altitudes for center stored routes which may differ from stored altitudes. The Captain will compare the plan altitude with the center stored altitude (pages 75-100.18), and if different, request the plan altitude from ATC.

d. Indicated mach number at check point.

e. Deviation from standard temperature at check point.

f. True air speed in knots at check point.

g. Wind-direction in tens of degrees (30=300°) and speed in knots (058) at check point.

h. Headwind or tailwind component at check point.

i. Ground speed at check point.

j. Segment time in minutes.

k. Segment burnout in hundreds of pounds.

l. Fuel remaining in hundreds of pounds at check point.

6) a. Wind vector and component used in determining descent performance data.

7) Summarized flight plans for other altitudes over the route. When the policy FPF is a reduced mach plan, a summary plan is included at standard mach.

   a. Highest flight level in thousands of feet (usually POD altitude).
   b. Planned takeoff gross weight.
   c. Total flight time enroute.
   d. Total burnout.
   e. Numbers in this space indicate amount of burnout in pounds for each minute of time gained based on flight time in Base Plan. "OOO" indicates this is the Base Plan. "XXX" indicates disregard this summary plan as flight time and fuel are greater than the Base plan. Amounts greater than 3094 appear as "3094".
   f. Mach number used to compute summary plan.

NOTE: An "X" in a summary line between "e" and "f" indicates that, due to the higher burnout at summary altitude, either the maximum ATOG or the maximum fuel capacity (or both) are exceeded.

8) Data required by ARTC.

   a. Flight identification.
   b. FAA aircraft type and equipment codes.
   c. True air speed during first cruise segment.
   d. Departure station.
   e. Planned departure time (GMT)
   f. Flight level planned for first segment in hundreds of feet.
   g. Planned route of flight. (If preferred, "PREFERRED" added; if center-stored, "C/S" added.)

9) Remarks - Three lines are reserved for Dispatchers' and/or Meteorologists' comments pertinent to the operation of the flight.

Gross Weight and Fuel Work Sheet (UF 1699)

72. PREPARE a Gross Weight and Fuel Work Sheet for all flights at flight planning offices, except as noted below. A copy of the form should accompany each flight and be filed with the flight papers.

A. Dispatchers and Captains may use it as the work sheet for computing fuel requirements for load planning purposes.

B. When the Captain agrees with the Dispatcher's fuel computation, or vice versa, he uses appropriate words such as agree, same, etc. without duplicating the previous computation.

EXCEPTION: When the Captain accepts the Flight Plan Forecast, it is not necessary to prepare the Gross Weight and Fuel Work Sheet.

APPENDIX C

AIRPORT PAIR ROUTE STRUCTURE PERFORMANCE STATISTICS AND MINIMUM ROUTE STRUCTURE WIND MILE PLOTS

ROUTE STRUCTURE COMPARISONS

PREFERRED ROUTE: GROUND, WIND AND TOTAL BENEFIT

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 11 ORD DEN

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	-.1 (-.02)	-.1 (-.02)	-.1 (-.02)	.1 (.01)	-.1 (-.02)	.1 (.01)
	+ .0 (.00)	+ -1.2 (-.14)	+ -.3 (-.04)	+ -1.2 (-.14)	+ 2.5 (.29)	+ -1.2 (-.14)	+ 2.5 (.29)
	= .0 (.00)	= -1.3 (-.15)	= -.5 (-.05)	= -1.3 (-.15)	= 2.6 (.30)	= -1.3 (-.15)	= 2.6 (.30)
SCI/NAFEC	.1 (.02)	.0 (.00)	.0 (.00)	.0 (.00)	.2 (.02)	.0 (.00)	.2 (.02)
	+ 1.2 (.14)	+ .0 (.00)	+ .9 (.10)	+ .0 (.00)	+ 3.7 (.43)	+ .0 (.00)	+ 3.7 (.43)
	= 1.3 (.15)	= .0 (.00)	= .9 (.10)	= .0 (.00)	= 3.9 (.45)	= .0 (.00)	= 3.9 (.45)
FAA/NAFEC	.1 (.02)	.0 (.00)	.0 (.00)	.0 (.00)	.2 (.02)	.0 (.00)	.2 (.02)
	+ .3 (.04)	+ -.9 (-.10)	+ .0 (.00)	+ -.9 (-.10)	+ 2.9 (.33)	+ -.9 (-.10)	+ 2.9 (.33)
	= .5 (.05)	= -.9 (-.10)	= .0 (.00)	= -.9 (-.10)	= 3.1 (.35)	= -.9 (-.10)	= 3.1 (.35)
SCI/FA/NAFEC	.1 (.02)	.0 (.00)	.0 (.00)	.0 (.00)	.2 (.02)	.0 (.00)	.2 (.02)
	+ 1.2 (.14)	+ .0 (.00)	+ .9 (.10)	+ .0 (.00)	+ 3.7 (.43)	+ .0 (.00)	+ 3.7 (.43)
	= 1.3 (.15)	= .0 (.00)	= .9 (.10)	= .0 (.00)	= 3.9 (.45)	= .0 (.00)	= 3.9 (.45)
VOR/A	-.1 (-.01)	-.2 (-.02)	-.2 (-.02)	-.2 (-.02)	.0 (.00)	-.2 (-.02)	.0 (.00)
	+ -2.5 (-.29)	+ -3.7 (-.43)	+ -2.9 (-.33)	+ -3.7 (-.43)	+ .0 (.00)	+ -3.7 (-.43)	+ .0 (.00)
	= -2.6 (-.30)	= -3.9 (-.45)	= -3.1 (-.35)	= -3.9 (-.45)	= .0 (.00)	= -3.9 (-.45)	= .0 (.00)
PRE-PLANNED	.1 (.02)	.0 (.00)	.0 (.00)	.0 (.00)	.2 (.02)	.0 (.00)	.2 (.02)
	+ 1.2 (.14)	+ .0 (.00)	+ .9 (.10)	+ .0 (.00)	+ 3.7 (.43)	+ .0 (.00)	+ 3.7 (.43)
	= 1.3 (.15)	= .0 (.00)	= .9 (.10)	= .0 (.00)	= 3.9 (.45)	= .0 (.00)	= 3.9 (.45)
VOR/C	-.1 (-.01)	-.2 (-.02)	-.2 (-.02)	-.2 (-.02)	.0 (.00)	-.2 (-.02)	.0 (.00)
	+ -2.5 (-.29)	+ -3.7 (-.43)	+ -2.9 (-.33)	+ -3.7 (-.43)	+ .0 (.00)	+ -3.7 (-.43)	+ .0 (.00)
	= -2.6 (-.30)	= -3.9 (-.45)	= -3.1 (-.35)	= -3.9 (-.45)	= .0 (.00)	= -3.9 (-.45)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ALTERNATE ROUTE BENEFIT: PREFERRED ROUTE, ADDITIONAL ROUTES AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 11 ORD DEN

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	-1.3 (-.15)	-.5 (-.05)	-1.3 (-.15)	2.6 (.30)	-1.3 (-.15)	2.6 (.30)
	+ .0 (.00)	+ .5 (.05)	+ .2 (.02)	+ .5 (.05)	+ -3.0 (-.34)	+ -2.4 (-.28)	+ -1.4 (-.16)
	= .0 (.00)	= -.9 (-.10)	= -.3 (-.03)	= -.9 (-.10)	= -.4 (-.05)	= -3.7 (-.43)	= 1.2 (.13)
SCI/NAFEC	1.3 (.15)	.0 (.00)	.9 (.10)	.0 (.00)	3.9 (.45)	.0 (.00)	3.9 (.45)
	+ -.5 (-.05)	+ .0 (.00)	+ -.3 (-.03)	+ .0 (.00)	+ -3.5 (-.40)	+ -2.9 (-.33)	+ -1.9 (-.22)
	= .9 (.10)	= .0 (.00)	= .6 (.07)	= .0 (.00)	= .5 (.05)	= -2.9 (-.33)	= 2.0 (.23)
FAA/NAFEC	.5 (.05)	-.9 (-.10)	.0 (.00)	-.9 (-.10)	3.1 (.35)	-.9 (-.10)	3.1 (.35)
	+ -.2 (-.02)	+ .3 (.03)	+ .0 (.00)	+ .3 (.03)	+ -3.2 (-.37)	+ -2.6 (-.30)	+ -1.6 (-.19)
	= .3 (.03)	= -.6 (-.07)	= .0 (.00)	= -.6 (-.07)	= -.2 (-.02)	= -3.5 (-.40)	= 1.4 (.16)
SCI/FA/NAFEC	1.3 (.15)	.0 (.00)	.9 (.10)	.0 (.00)	3.9 (.45)	.0 (.00)	3.9 (.45)
	+ -.5 (-.05)	+ .0 (.00)	+ -.3 (-.03)	+ .0 (.00)	+ -3.5 (-.40)	+ -2.9 (-.33)	+ -1.9 (-.22)
	= .9 (.10)	= .0 (.00)	= .6 (.07)	= .0 (.00)	= .5 (.05)	= -2.9 (-.33)	= 2.0 (.23)
VOR/A	-2.5 (-.30)	-3.9 (-.45)	-3.1 (-.35)	-3.9 (-.45)	.0 (.00)	-3.9 (-.45)	.0 (.00)
	+ 3.0 (.34)	+ 3.5 (.40)	+ 3.2 (.37)	+ 3.5 (.40)	+ .0 (.00)	+ .6 (.07)	+ 1.6 (.18)
	= .4 (.05)	= -.5 (-.05)	= .2 (.02)	= -.5 (-.05)	= .0 (.00)	= -3.3 (-.38)	= 1.6 (.18)
PRE-PLANNED	1.3 (.15)	.0 (.00)	.9 (.10)	.0 (.00)	3.9 (.45)	.0 (.00)	3.9 (.45)
	+ 2.4 (.28)	+ 2.9 (.33)	+ 2.6 (.30)	+ 2.9 (.33)	+ -.6 (-.07)	+ .0 (.00)	+ 1.0 (.11)
	= 3.7 (.43)	= 2.9 (.33)	= 3.5 (.40)	= 2.9 (.33)	= 3.3 (.38)	= .0 (.00)	= 4.9 (.56)
VOR/C	-2.6 (-.30)	-3.9 (-.45)	-3.1 (-.35)	-3.9 (-.45)	.0 (.00)	-3.9 (-.45)	.0 (.00)
	+ 1.4 (.16)	+ 1.9 (.22)	+ 1.6 (.19)	+ 1.9 (.22)	+ -1.6 (-.18)	+ -1.0 (-.11)	+ .0 (.00)
	= -1.2 (-.13)	= -2.0 (-.23)	= -1.4 (-.16)	= -2.0 (-.23)	= -1.6 (-.18)	= -4.9 (-.56)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ROUTE STRUCTURE BENEFIT: GROUND, WIND AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 11 ORD DEN

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAPEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	-.1 (-.02)	-.1 (-.02)	-.1 (-.02)	.1 (.01)	-.1 (-.02)	.1 (.01)
	+ .0 (.00)	+ -.7 (-.08)	+ -.1 (-.01)	+ -.7 (-.08)	+ -.5 (-.05)	+ -3.6 (-.42)	+ 1.1 (.13)
	= .0 (.00)	= -.9 (-.10)	= -.3 (-.03)	= -.9 (-.10)	= -.4 (-.05)	= -3.7 (-.43)	= 1.2 (.13)
SCI/NAFEC	.1 (.02)	.0 (.00)	.0 (.00)	.0 (.00)	.2 (.02)	.0 (.00)	.2 (.02)
	+ .7 (.08)	+ .0 (.00)	+ .6 (.07)	+ .0 (.00)	+ .3 (.03)	+ -2.9 (-.33)	+ 1.8 (.21)
	= .9 (.10)	= .0 (.00)	= .6 (.07)	= .0 (.00)	= .5 (.05)	= -2.9 (-.33)	= 2.0 (.23)
FAA/NAFEC	.1 (.02)	.0 (.00)	.0 (.00)	.0 (.00)	.2 (.02)	.0 (.00)	.2 (.02)
	+ .1 (.01)	+ -.6 (-.07)	+ .0 (.00)	+ -.6 (-.07)	+ -.3 (-.04)	+ -3.5 (-.40)	+ 1.2 (.14)
	= .3 (.03)	= -.6 (-.07)	= .0 (.00)	= -.6 (-.07)	= -.2 (-.02)	= -3.5 (-.40)	= 1.4 (.16)
SCI/FA/NAFEC	.1 (.02)	.0 (.00)	.0 (.00)	.0 (.00)	.2 (.02)	.0 (.00)	.2 (.02)
	+ .7 (.08)	+ .0 (.00)	+ .6 (.07)	+ .0 (.00)	+ .3 (.03)	+ -2.9 (-.33)	+ 1.8 (.21)
	= .9 (.10)	= .0 (.00)	= .6 (.07)	= .0 (.00)	= .5 (.05)	= -2.9 (-.33)	= 2.0 (.23)
VOR/A	-.1 (-.01)	-.2 (-.02)	-.2 (-.02)	-.2 (-.02)	.0 (.00)	-.2 (-.02)	.0 (.00)
	+ .5 (.05)	+ -.3 (-.03)	+ .3 (.04)	+ -.3 (-.03)	+ .0 (.00)	+ -3.1 (-.36)	+ 1.6 (.18)
	= .4 (.05)	= -.5 (-.05)	= .2 (.02)	= -.5 (-.05)	= .0 (.00)	= -3.3 (-.38)	= 1.6 (.18)
PRE-PLANNED	.1 (.02)	.0 (.00)	.0 (.00)	.0 (.00)	.2 (.02)	.0 (.00)	.2 (.02)
	+ 3.6 (.41)	+ 2.9 (.33)	+ 3.5 (.40)	+ 2.9 (.33)	+ 3.1 (.36)	+ .0 (.00)	+ 4.7 (.54)
	= 3.7 (.43)	= 2.9 (.33)	= 3.5 (.40)	= 2.9 (.33)	= 3.3 (.38)	= .0 (.00)	= 4.9 (.56)
VOR/C	-.1 (-.01)	-.2 (-.02)	-.2 (-.02)	-.2 (-.02)	.0 (.00)	-.2 (-.02)	.0 (.00)
	+ -1.1 (-.13)	+ -1.8 (-.21)	+ -1.2 (-.14)	+ -1.8 (-.21)	+ -1.6 (-.18)	+ -4.7 (-.54)	+ .0 (.00)
	= -1.2 (-.13)	= -2.0 (-.23)	= -1.4 (-.16)	= -2.0 (-.23)	= -1.6 (-.18)	= -4.9 (-.56)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

PREFERRED ROUTE: GROUND, WIND AND TOTAL BENEFIT

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 2: DEN ORD

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	2.0 (.28)	3.5 (.48)	3.5 (.48)	5.2 (.71)	.0 (.00)	5.2 (.71)
	+ .0 (.00)	+ -.1 (-.02)	+ -1.1 (-.15)	+ -1.1 (-.15)	+ 3.3 (.45)	+ .0 (.00)	+ 3.3 (.45)
	= .0 (.00)	= 1.9 (.27)	= 2.4 (.33)	= 2.4 (.33)	= 8.5 (1.16)	= .0 (.00)	= 8.5 (1.16)
SCI/NAFEC	-2.0 (-.28)	.0 (.00)	1.4 (.20)	1.4 (.20)	3.2 (.43)	-2.0 (-.28)	3.2 (.43)
	+ .1 (.02)	+ .0 (.00)	+ -1.0 (-.14)	+ -1.0 (-.14)	+ 3.4 (.46)	+ .1 (.02)	+ 3.4 (.46)
	= -1.9 (-.27)	= .0 (.00)	= .5 (.06)	= .5 (.06)	= 6.6 (.90)	= -1.9 (-.27)	= 6.6 (.90)
FAA/NAFEC	-3.5 (-.48)	-1.4 (-.20)	.0 (.00)	.0 (.00)	1.7 (.24)	-3.5 (-.48)	1.7 (.24)
	+ 1.1 (.15)	+ 1.0 (.14)	+ .0 (.00)	+ .0 (.00)	+ 4.4 (.60)	+ 1.1 (.15)	+ 4.4 (.60)
	= -2.4 (-.33)	= -.5 (-.06)	= .0 (.00)	= .0 (.00)	= 6.1 (.84)	= -2.4 (-.33)	= 6.1 (.84)
SCI/FA/NAFEC	-3.5 (-.48)	-1.4 (-.20)	.0 (.00)	.0 (.00)	1.7 (.24)	-3.5 (-.48)	1.7 (.24)
	+ 1.1 (.15)	+ 1.0 (.14)	+ .0 (.00)	+ .0 (.00)	+ 4.4 (.60)	+ 1.1 (.15)	+ 4.4 (.60)
	= -2.4 (-.33)	= -.5 (-.06)	= .0 (.00)	= .0 (.00)	= 6.1 (.84)	= -2.4 (-.33)	= 6.1 (.84)
VOR/A	-5.2 (-.72)	-3.2 (-.44)	-1.7 (-.24)	-1.7 (-.24)	.0 (.00)	-5.2 (-.72)	.0 (.00)
	+ -3.3 (-.45)	+ -3.4 (-.47)	+ -4.4 (-.60)	+ -4.4 (-.60)	+ .0 (.00)	+ -3.3 (-.45)	+ .0 (.00)
	= -8.5 (-1.18)	= -6.6 (-.91)	= -6.1 (-.84)	= -6.1 (-.84)	= .0 (.00)	= -8.5 (-1.18)	= .0 (.00)
PRE-PLANNED	.0 (.00)	2.0 (.28)	3.5 (.48)	3.5 (.48)	5.2 (.71)	.0 (.00)	5.2 (.71)
	+ .0 (.00)	+ -.1 (-.02)	+ -1.1 (-.15)	+ -1.1 (-.15)	+ 3.3 (.45)	+ .0 (.00)	+ 3.3 (.45)
	= .0 (.00)	= 1.9 (.27)	= 2.4 (.33)	= 2.4 (.33)	= 8.5 (1.16)	= .0 (.00)	= 8.5 (1.16)
VOR/C	-5.2 (-.72)	-3.2 (-.44)	-1.7 (-.24)	-1.7 (-.24)	.0 (.00)	-5.2 (-.72)	.0 (.00)
	+ -3.3 (-.45)	+ -3.4 (-.47)	+ -4.4 (-.60)	+ -4.4 (-.60)	+ .0 (.00)	+ -3.3 (-.45)	+ .0 (.00)
	= -8.5 (-1.18)	= -6.6 (-.91)	= -6.1 (-.84)	= -6.1 (-.84)	= .0 (.00)	= -8.5 (-1.18)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ALTERNATE ROUTE BENEFIT: PREFERRED ROUTE, ADDITIONAL ROUTES AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 21 DEN ORD

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	1.9 (.27)	2.4 (.33)	2.4 (.33)	8.5 (1.17)	.0 (.00)	8.5 (1.16)
	+ .0 (.00)	+ .0 (.00)	+ -2.2 (-.30)	+ -2.2 (-.30)	+ -2.1 (-.28)	+ -1.0 (-.14)	+ -1.2 (-.17)
	= .0 (.00)	= 1.9 (.27)	= .2 (.03)	= .2 (.03)	= 6.4 (.88)	= -1.0 (-.14)	= 7.3 (1.00)
SCI/NAFEC	-1.9 (-.27)	.0 (.00)	.5 (.06)	.5 (.06)	6.6 (.90)	-1.9 (-.27)	6.6 (.90)
	+ .0 (.00)	+ .0 (.00)	+ -2.2 (-.30)	+ -2.2 (-.30)	+ -2.1 (-.28)	+ -1.0 (-.14)	+ -1.2 (-.17)
	= -1.9 (-.27)	= .0 (.00)	= -1.7 (-.24)	= -1.7 (-.24)	= 4.5 (.62)	= -2.9 (-.41)	= 5.4 (.74)
FAA/NAFEC	-2.4 (-.33)	-.5 (-.06)	.0 (.00)	.0 (.00)	6.1 (.84)	-2.4 (-.33)	6.1 (.84)
	+ 2.2 (.30)	+ 2.2 (.30)	+ .0 (.00)	+ .0 (.00)	+ .1 (.02)	+ 1.2 (.16)	+ 1.0 (.13)
	= -.2 (-.03)	= 1.7 (.24)	= .0 (.00)	= .0 (.00)	= 6.2 (.86)	= -1.2 (-.17)	= 7.1 (.97)
SCI/FA/NAFEC	-2.4 (-.33)	-.5 (-.06)	.0 (.00)	.0 (.00)	6.1 (.84)	-2.4 (-.33)	6.1 (.84)
	+ 2.2 (.30)	+ 2.2 (.30)	+ .0 (.00)	+ .0 (.00)	+ .1 (.02)	+ 1.2 (.16)	+ 1.0 (.13)
	= -.2 (-.03)	= 1.7 (.24)	= .0 (.00)	= .0 (.00)	= 6.2 (.86)	= -1.2 (-.17)	= 7.1 (.97)
VOR/A	-8.5 (-1.18)	-6.6 (-.91)	-6.1 (-.85)	-6.1 (-.85)	.0 (.00)	-8.5 (-1.18)	.0 (.00)
	+ 2.1 (.28)	+ 2.1 (.28)	+ -.1 (-.02)	+ -.1 (-.02)	+ .0 (.00)	+ 1.0 (.14)	+ .8 (.12)
	= -6.4 (-.89)	= -4.5 (-.62)	= -6.2 (-.86)	= -6.2 (-.86)	= .0 (.00)	= -7.5 (-1.04)	= .8 (.12)
PRE-PLANNED	.0 (.00)	1.9 (.27)	2.4 (.33)	2.4 (.33)	8.5 (1.17)	.0 (.00)	8.5 (1.16)
	+ 1.0 (.14)	+ 1.0 (.14)	+ -1.2 (-.16)	+ -1.2 (-.16)	+ -1.0 (-.14)	+ .0 (.00)	+ -.2 (-.02)
	= 1.0 (.14)	= 2.9 (.41)	= 1.2 (.17)	= 1.2 (.17)	= 7.5 (1.02)	= .0 (.00)	= 8.3 (1.14)
VOR/C	-8.5 (-1.18)	-6.6 (-.91)	-6.1 (-.85)	-6.1 (-.85)	.0 (.00)	-8.5 (-1.18)	.0 (.00)
	+ 1.2 (.17)	+ 1.2 (.17)	+ -1.0 (-.13)	+ -1.0 (-.13)	+ -.8 (-.12)	+ .2 (.02)	+ .0 (.00)
	= -7.3 (-1.01)	= -5.4 (-.74)	= -7.1 (-.98)	= -7.1 (-.98)	= -.8 (-.12)	= -8.3 (-1.15)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ROUTE STRUCTURE BENEFIT: GROUND, WIND AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 21 DEN ORD

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	2.0 (.28)	3.5 (.48)	3.5 (.48)	5.2 (.72)	.0 (.00)	5.2 (.72)
	+ .0 (.00)	+ -.1 (-.02)	+ -3.3 (-.45)	+ -3.3 (-.45)	+ 1.2 (.17)	+ -1.0 (-.14)	+ 2.1 (.28)
	= .0 (.00)	= 1.9 (.27)	= .2 (.03)	= .2 (.03)	= 6.4 (.88)	= -1.0 (-.14)	= 7.3 (1.00)
SCI/NAFEC	-2.0 (-.28)	.0 (.00)	1.4 (.20)	1.4 (.20)	3.2 (.44)	-2.0 (-.28)	3.2 (.43)
	+ .1 (.02)	+ .0 (.00)	+ -3.2 (-.44)	+ -3.2 (-.44)	+ 1.3 (.18)	+ -.9 (-.13)	+ 2.2 (.30)
	= -1.9 (-.27)	= .0 (.00)	= -1.7 (-.24)	= -1.7 (-.24)	= 4.5 (.62)	= -2.9 (-.41)	= 5.4 (.74)
FAA/NAFEC	-3.5 (-.48)	-1.4 (-.20)	.0 (.00)	.0 (.00)	1.7 (.24)	-3.5 (-.48)	1.7 (.24)
	+ 3.3 (.46)	+ 3.2 (.44)	+ .0 (.00)	+ .0 (.00)	+ 4.5 (.62)	+ 2.3 (.31)	+ 5.4 (.73)
	= -.2 (-.03)	= 1.7 (.24)	= .0 (.00)	= .0 (.00)	= 6.2 (.86)	= -1.2 (-.17)	= 7.1 (.97)
SCI/FA/NAFEC	-3.5 (-.48)	-1.4 (-.20)	.0 (.00)	.0 (.00)	1.7 (.24)	-3.5 (-.48)	1.7 (.24)
	+ 3.3 (.46)	+ 3.2 (.44)	+ .0 (.00)	+ .0 (.00)	+ 4.5 (.62)	+ 2.3 (.31)	+ 5.4 (.73)
	= -.2 (-.03)	= 1.7 (.24)	= .0 (.00)	= .0 (.00)	= 6.2 (.86)	= -1.2 (-.17)	= 7.1 (.97)
VOR/A	-5.2 (-.72)	-3.2 (-.44)	-1.7 (-.24)	-1.7 (-.24)	.0 (.00)	-5.2 (-.72)	.0 (.00)
	+ -1.2 (-.17)	+ -1.3 (-.19)	+ -4.5 (-.62)	+ -4.5 (-.62)	+ .0 (.00)	+ -2.2 (-.31)	+ .8 (.12)
	= -6.4 (-.89)	= -4.5 (-.62)	= -6.2 (-.86)	= -6.2 (-.86)	= .0 (.00)	= -7.5 (-1.04)	= .8 (.12)
PRE-PLANNED	.0 (.00)	2.0 (.28)	3.5 (.48)	3.5 (.48)	5.2 (.72)	.0 (.00)	5.2 (.72)
	+ 1.0 (.14)	+ .9 (.13)	+ -2.3 (-.31)	+ -2.3 (-.31)	+ 2.2 (.31)	+ .0 (.00)	+ 3.1 (.42)
	= 1.0 (.14)	= 2.9 (.41)	= 1.2 (.17)	= 1.2 (.17)	= 7.5 (1.02)	= .0 (.00)	= 8.3 (1.14)
VOR/C	-5.2 (-.72)	-3.2 (-.44)	-1.7 (-.24)	-1.7 (-.24)	.0 (.00)	-5.2 (-.72)	.0 (.00)
	+ -2.1 (-.29)	+ -2.2 (-.30)	+ -5.4 (-.74)	+ -5.4 (-.74)	+ -.8 (-.12)	+ -3.1 (-.43)	+ .0 (.00)
	= -7.3 (-1.01)	= -5.4 (-.74)	= -7.1 (-.98)	= -7.1 (-.98)	= -.8 (-.12)	= -8.3 (-1.15)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

PREFERRED ROUTE: GROUND, WIND AND TOTAL BENEFIT

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 3: ORD LAX

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	-.4 (-.02)	4.4 (.26)	-.4 (-.02)	7.0 (.41)	-.4 (-.02)	7.0 (.41)
	+ .0 (.00)	+ -2.8 (-.16)	+ 4.4 (.26)	+ -2.8 (-.16)	+ 16.4 (.95)	+ -2.8 (-.16)	+ 16.4 (.95)
	= .0 (.00)	= -3.2 (-.19)	= 8.8 (.52)	= -3.2 (-.19)	= 23.4 (1.36)	= -3.2 (-.19)	= 23.4 (1.36)
SCI/NAFEC	.4 (.02)	.0 (.00)	4.8 (.28)	.0 (.00)	7.4 (.43)	.0 (.00)	7.4 (.43)
	+ 2.8 (.16)	+ .0 (.00)	+ 7.2 (.42)	+ .0 (.00)	+ 19.1 (1.11)	+ .0 (.00)	+ 19.1 (1.11)
	= 3.2 (.19)	= .0 (.00)	= 12.0 (.70)	= .0 (.00)	= 26.5 (1.54)	= .0 (.00)	= 26.5 (1.54)
FAA/NAFEC	-4.4 (-.26)	-4.8 (-.28)	.0 (.00)	-4.8 (-.28)	2.6 (.15)	-4.8 (-.28)	2.6 (.15)
	+ -4.4 (-.26)	+ -7.2 (-.43)	+ .0 (.00)	+ -7.2 (-.43)	+ 11.9 (.70)	+ -7.2 (-.43)	+ 11.9 (.70)
	= -8.8 (-.52)	=-12.0 (-.71)	= .0 (.00)	=-12.0 (-.71)	= 14.5 (.85)	=-12.0 (-.71)	= 14.5 (.85)
SCI/FA/NAFEC	.4 (.02)	.0 (.00)	4.8 (.28)	.0 (.00)	7.4 (.43)	.0 (.00)	7.4 (.43)
	+ 2.8 (.16)	+ .0 (.00)	+ 7.2 (.42)	+ .0 (.00)	+ 19.1 (1.11)	+ .0 (.00)	+ 19.1 (1.11)
	= 3.2 (.19)	= .0 (.00)	= 12.0 (.70)	= .0 (.00)	= 26.5 (1.54)	= .0 (.00)	= 26.5 (1.54)
VOR/A	-7.0 (-.41)	-7.4 (-.44)	-2.6 (-.15)	-7.4 (-.44)	.0 (.00)	-7.4 (-.44)	.0 (.00)
	+-16.4 (-.97)	+-19.1 (-1.13)	+-11.9 (-.70)	+-19.1 (-1.13)	+ .0 (.00)	+-19.1 (-1.13)	+ .0 (.00)
	=-23.4 (-1.38)	=-26.5 (-1.57)	=-14.5 (-.85)	=-26.5 (-1.57)	= .0 (.00)	=-26.5 (-1.57)	= .0 (.00)
PRE-PLANNED	.4 (.02)	.0 (.00)	4.8 (.28)	.0 (.00)	7.4 (.43)	.0 (.00)	7.4 (.43)
	+ 2.8 (.16)	+ .0 (.00)	+ 7.2 (.42)	+ .0 (.00)	+ 19.1 (1.11)	+ .0 (.00)	+ 19.1 (1.11)
	= 3.2 (.19)	= .0 (.00)	= 12.0 (.70)	= .0 (.00)	= 26.5 (1.54)	= .0 (.00)	= 26.5 (1.54)
VOR/C	-7.0 (-.41)	-7.4 (-.44)	-2.6 (-.15)	-7.4 (-.44)	.0 (.00)	-7.4 (-.44)	.0 (.00)
	+-16.4 (-.97)	+-19.1 (-1.13)	+-11.9 (-.70)	+-19.1 (-1.13)	+ .0 (.00)	+-19.1 (-1.13)	+ .0 (.00)
	=-23.4 (-1.38)	=-26.5 (-1.57)	=-14.5 (-.85)	=-26.5 (-1.57)	= .0 (.00)	=-26.5 (-1.57)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ALTERNATE ROUTE BENEFIT: PREFERRED ROUTE, ADDITIONAL ROUTES AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 31 ORD LAX

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00) + .0 (.00) = .0 (.00)	-3.2 (-.19) + 4.4 (.26) = 1.2 (.07)	8.8 (.53) + -4.7 (-.28) = 4.2 (.25)	-3.2 (-.19) + 4.4 (.26) = 1.2 (.07)	23.4 (1.39) +-12.0 (-.71) = 11.4 (.68)	-3.2 (-.19) + .5 (.03) = -2.7 (-.16)	23.4 (1.38) + -6.8 (-.41) = 16.5 (.98)
SCI/NAFEC	3.2 (.19) + -4.4 (-.26) = -1.2 (-.07)	.0 (.00) + .0 (.00) = .0 (.00)	12.0 (.72) + -9.1 (-.54) = 2.9 (.18)	.0 (.00) + .0 (.00) = .0 (.00)	26.5 (1.58) +-16.4 (-.97) = 10.2 (.60)	.0 (.00) + -3.9 (-.23) = -3.9 (-.23)	26.5 (1.57) +-11.2 (-.66) = 15.3 (.91)
FAA/NAFEC	-8.8 (-.53) + 4.7 (.28) = -4.2 (-.25)	-12.0 (-.72) + 9.1 (.54) = -2.9 (-.18)	.0 (.00) + .0 (.00) = .0 (.00)	-12.0 (-.72) + 9.1 (.54) = -2.9 (-.18)	14.5 (.86) + -7.3 (-.43) = 7.2 (.43)	-12.0 (-.72) + 5.2 (.31) = -6.8 (-.41)	14.5 (.86) + -2.2 (-.13) = 12.4 (.73)
SCI/FA/NAFEC	3.2 (.19) + -4.4 (-.26) = -1.2 (-.07)	.0 (.00) + .0 (.00) = .0 (.00)	12.0 (.72) + -9.1 (-.54) = 2.9 (.18)	.0 (.00) + .0 (.00) = .0 (.00)	26.5 (1.58) +-16.4 (-.97) = 10.2 (.60)	.0 (.00) + -3.9 (-.23) = -3.9 (-.23)	26.5 (1.57) +-11.2 (-.66) = 15.3 (.91)
VOR/A	-23.4 (-1.40) + 12.0 (.72) =-11.4 (-.68)	-26.5 (-1.59) + 16.4 (.98) =-10.2 (-.61)	-14.5 (-.87) + 7.3 (.44) = -7.2 (-.43)	-26.5 (-1.59) + 16.4 (.98) =-10.2 (-.61)	.0 (.00) + .0 (.00) = .0 (.00)	-26.5 (-1.59) + 12.5 (.75) =-14.1 (-.84)	.0 (.00) + 5.2 (.31) = 5.2 (.31)
PRE-PLANNED	3.2 (.19) + -.5 (-.03) = 2.7 (.16)	.0 (.00) + 3.9 (.23) = 3.9 (.23)	12.0 (.72) + -5.2 (-.31) = 6.8 (.41)	.0 (.00) + 3.9 (.23) = 3.9 (.23)	26.5 (1.58) +-12.5 (-.74) = 14.1 (.84)	.0 (.00) + .0 (.00) = .0 (.00)	26.5 (1.57) + -7.3 (-.43) = 19.2 (1.14)
VOR/C	-23.4 (-1.40) + 6.8 (.41) =-16.5 (-.99)	-26.5 (-1.59) + 11.2 (.67) =-15.3 (-.92)	-14.5 (-.87) + 2.2 (.13) =-12.4 (-.74)	-26.5 (-1.59) + 11.2 (.67) =-15.3 (-.92)	.0 (.00) + -5.2 (-.31) = -5.2 (-.31)	-26.5 (-1.59) + 7.3 (.44) =-19.2 (-1.15)	.0 (.00) + .0 (.00) = .0 (.00)

ROUTE STRUCTURE COMPARISONS

ROUTE STRUCTURE BENEFIT: GROUND, WIND AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 31: ORD LAX

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	-.4 (-.02)	4.4 (.26)	-.4 (-.02)	7.0 (.42)	-.4 (-.02)	7.0 (.41)
	+ .0 (.00)	+ 1.6 (.10)	+ -.3 (-.02)	+ 1.6 (.10)	+ 4.4 (.26)	+ -2.3 (-.14)	+ 9.5 (.56)
	= .0 (.00)	= 1.2 (.07)	= 4.2 (.25)	= 1.2 (.07)	= 11.4 (.68)	= -2.7 (-.16)	= 16.5 (.98)
SCI/NAFEC	.4 (.02)	.0 (.00)	4.8 (.29)	.0 (.00)	7.4 (.44)	.0 (.00)	7.4 (.44)
	+ -1.6 (-.10)	+ .0 (.00)	+ -1.8 (-.11)	+ .0 (.00)	+ 2.8 (.17)	+ -3.9 (-.23)	+ 7.9 (.47)
	= -1.2 (-.07)	= .0 (.00)	= 2.9 (.18)	= .0 (.00)	= 10.2 (.60)	= -3.9 (-.23)	= 15.3 (.91)
FAA/NAFEC	-4.4 (-.26)	-4.8 (-.29)	.0 (.00)	-4.8 (-.29)	2.6 (.15)	-4.8 (-.29)	2.6 (.15)
	+ .3 (.02)	+ 1.8 (.11)	+ .0 (.00)	+ 1.8 (.11)	+ 4.6 (.28)	+ -2.0 (-.12)	+ 9.8 (.58)
	= -4.2 (-.25)	= -2.9 (-.18)	= .0 (.00)	= -2.9 (-.18)	= 7.2 (.43)	= -6.8 (-.41)	= 12.4 (.73)
SCI/FA/NAFEC	.4 (.02)	.0 (.00)	4.8 (.29)	.0 (.00)	7.4 (.44)	.0 (.00)	7.4 (.44)
	+ -1.6 (-.10)	+ .0 (.00)	+ -1.8 (-.11)	+ .0 (.00)	+ 2.8 (.17)	+ -3.9 (-.23)	+ 7.9 (.47)
	= -1.2 (-.07)	= .0 (.00)	= 2.9 (.18)	= .0 (.00)	= 10.2 (.60)	= -3.9 (-.23)	= 15.3 (.91)
VOR/A	-7.0 (-.42)	-7.4 (-.44)	-2.6 (-.15)	-7.4 (-.44)	.0 (.00)	-7.4 (-.44)	.0 (.00)
	+ -4.4 (-.26)	+ -2.8 (-.17)	+ -4.6 (-.28)	+ -2.8 (-.17)	+ .0 (.00)	+ -6.7 (-.40)	+ 5.2 (.31)
	=-11.4 (-.68)	=-10.2 (-.61)	= -7.2 (-.43)	=-10.2 (-.61)	= .0 (.00)	=-14.1 (-.84)	= 5.2 (.31)
PRE-PLANNED	.4 (.02)	.0 (.00)	4.8 (.29)	.0 (.00)	7.4 (.44)	.0 (.00)	7.4 (.44)
	+ 2.3 (.14)	+ 3.9 (.23)	+ 2.0 (.12)	+ 3.9 (.23)	+ 6.7 (.40)	+ .0 (.00)	+ 11.8 (.70)
	= 2.7 (.16)	= 3.9 (.23)	= 6.8 (.41)	= 3.9 (.23)	= 14.1 (.84)	= .0 (.00)	= 19.2 (1.14)
VOR/C	-7.0 (-.42)	-7.4 (-.44)	-2.6 (-.15)	-7.4 (-.44)	.0 (.00)	-7.4 (-.44)	.0 (.00)
	+ -9.5 (-.57)	+ -7.9 (-.47)	+ -9.8 (-.58)	+ -7.9 (-.47)	+ -5.2 (-.31)	+-11.8 (-.71)	+ .0 (.00)
	=-16.5 (-.99)	=-15.3 (-.92)	=-12.4 (-.74)	=-15.3 (-.92)	= -5.2 (-.31)	=-19.2 (-1.15)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

PREFERRED ROUTE: GROUND, WIND AND TOTAL BENEFIT

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR #1 LAX ORD

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	5.7 (.41)	-1.0 (-.07)	-1.0 (-.07)	13.4 (.97)	-1.0 (-.07)	13.4 (.97)
	+ .0 (.00)	+ 4.2 (.31)	+ .6 (.05)	+ .6 (.05)	+ 2.9 (.21)	+ .6 (.05)	+ 2.9 (.21)
	= .0 (.00)	= 10.0 (.72)	= -.3 (-.02)	= -.3 (-.02)	= 16.4 (1.18)	= -.3 (-.02)	= 16.4 (1.18)
SCI/NAFEC	-5.7 (-.42)	.0 (.00)	-6.7 (-.49)	-6.7 (-.49)	7.7 (.55)	-6.7 (-.49)	7.7 (.55)
	+ -4.2 (-.31)	+ .0 (.00)	+ -3.6 (-.26)	+ -3.6 (-.26)	+ -1.3 (-.09)	+ -3.6 (-.26)	+ -1.3 (-.09)
	=-10.0 (-.73)	= .0 (.00)	=-10.3 (-.75)	=-10.3 (-.75)	= 6.4 (.46)	=-10.3 (-.75)	= 6.4 (.46)
FAA/NAFEC	1.0 (.07)	6.7 (.48)	.0 (.00)	.0 (.00)	14.4 (1.04)	.0 (.00)	14.4 (1.04)
	+ -.6 (-.05)	+ 3.6 (.26)	+ .0 (.00)	+ .0 (.00)	+ 2.3 (.17)	+ .0 (.00)	+ 2.3 (.17)
	= .3 (.02)	= 10.3 (.75)	= .0 (.00)	= .0 (.00)	= 16.7 (1.20)	= .0 (.00)	= 16.7 (1.20)
SCI/FA/NAFEC	1.0 (.07)	6.7 (.48)	.0 (.00)	.0 (.00)	14.4 (1.04)	.0 (.00)	14.4 (1.04)
	+ -.6 (-.05)	+ 3.6 (.26)	+ .0 (.00)	+ .0 (.00)	+ 2.3 (.17)	+ .0 (.00)	+ 2.3 (.17)
	= .3 (.02)	= 10.3 (.75)	= .0 (.00)	= .0 (.00)	= 16.7 (1.20)	= .0 (.00)	= 16.7 (1.20)
VOR/A	-13.4 (-.98)	-7.7 (-.56)	-14.4 (-1.05)	-14.4 (-1.05)	.0 (.00)	-14.4 (-1.05)	.0 (.00)
	+ -2.9 (-.21)	+ 1.3 (.09)	+ -2.3 (-.17)	+ -2.3 (-.17)	+ .0 (.00)	+ -2.3 (-.17)	+ .0 (.00)
	=-16.4 (-1.19)	= -6.4 (-.46)	=-16.7 (-1.22)	=-16.7 (-1.22)	= .0 (.00)	=-16.7 (-1.22)	= .0 (.00)
PRE-PLANNED	1.0 (.07)	6.7 (.48)	.0 (.00)	.0 (.00)	14.4 (1.04)	.0 (.00)	14.4 (1.04)
	+ -.6 (-.05)	+ 3.6 (.26)	+ .0 (.00)	+ .0 (.00)	+ 2.3 (.17)	+ .0 (.00)	+ 2.3 (.17)
	= .3 (.02)	= 10.3 (.75)	= .0 (.00)	= .0 (.00)	= 16.7 (1.20)	= .0 (.00)	= 16.7 (1.20)
VOR/C	-13.4 (-.98)	-7.7 (-.56)	-14.4 (-1.05)	-14.4 (-1.05)	.0 (.00)	-14.4 (-1.05)	.0 (.00)
	+ -2.9 (-.21)	+ 1.3 (.09)	+ -2.3 (-.17)	+ -2.3 (-.17)	+ .0 (.00)	+ -2.3 (-.17)	+ .0 (.00)
	=-16.4 (-1.19)	= -6.4 (-.46)	=-16.7 (-1.22)	=-16.7 (-1.22)	= .0 (.00)	=-16.7 (-1.22)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ALTERNATE ROUTE BENEFIT: PREFERRED ROUTE, ADDITIONAL ROUTES AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 41 LAX ORD

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	10.0 (.73)	-.3 (-.02)	-.3 (-.02)	16.4 (1.19)	-.3 (-.02)	16.4 (1.19)
	+ .0 (.00)	+ -8.4 (-.61)	+ -.5 (-.04)	+ -.5 (-.04)	+-10.2 (-.74)	+ -1.8 (-.13)	+ -8.5 (-.62)
	= .0 (.00)	= 1.6 (.11)	= -.9 (-.06)	= -.9 (-.06)	= 6.2 (.45)	= -2.1 (-.15)	= 7.9 (.57)
SCI/NAFEC	-10.0 (-.73)	.0 (.00)	-10.3 (-.75)	-10.3 (-.75)	6.4 (.47)	-10.3 (-.76)	6.4 (.46)
	+ 8.4 (.62)	+ .0 (.00)	+ 7.9 (.58)	+ 7.9 (.58)	+ -1.7 (-.13)	+ 6.6 (.49)	+ -.1 (-.01)
	= -1.6 (-.11)	= .0 (.00)	= -2.4 (-.18)	= -2.4 (-.18)	= 4.6 (.34)	= -3.7 (-.27)	= 6.3 (.46)
FAA/NAFEC	.3 (.02)	10.3 (.75)	.0 (.00)	.0 (.00)	16.7 (1.22)	.0 (.00)	16.7 (1.21)
	+ .5 (.04)	+ -7.9 (-.58)	+ .0 (.00)	+ .0 (.00)	+ -9.6 (-.70)	+ -1.2 (-.09)	+ -7.9 (-.58)
	= .9 (.06)	= 2.4 (.18)	= .0 (.00)	= .0 (.00)	= 7.1 (.52)	= -1.2 (-.09)	= 8.7 (.64)
SCI/FA/NAFEC	.3 (.02)	10.3 (.75)	.0 (.00)	.0 (.00)	16.7 (1.22)	.0 (.00)	16.7 (1.21)
	+ .5 (.04)	+ -7.9 (-.58)	+ .0 (.00)	+ .0 (.00)	+ -9.6 (-.70)	+ -1.2 (-.09)	+ -7.9 (-.58)
	= .9 (.06)	= 2.4 (.18)	= .0 (.00)	= .0 (.00)	= 7.1 (.52)	= -1.2 (-.09)	= 8.7 (.64)
VOR/A	-16.4 (-1.20)	-6.4 (-.47)	-16.7 (-1.22)	-16.7 (-1.22)	.0 (.00)	-16.7 (-1.22)	.0 (.00)
	+ 10.2 (.74)	+ 1.7 (.13)	+ 9.6 (.70)	+ 9.6 (.70)	+ .0 (.00)	+ 8.4 (.61)	+ 1.7 (.12)
	= -6.2 (-.45)	= -4.6 (-.34)	= -7.1 (-.52)	= -7.1 (-.52)	= .0 (.00)	= -8.3 (-.61)	= 1.7 (.12)
PRE-PLANNED	.3 (.02)	10.3 (.75)	.0 (.00)	.0 (.00)	16.7 (1.22)	.0 (.00)	16.7 (1.21)
	+ 1.8 (.13)	+ -6.6 (-.49)	+ 1.2 (.09)	+ 1.2 (.09)	+ -8.4 (-.61)	+ .0 (.00)	+ -6.7 (-.49)
	= 2.1 (.15)	= 3.7 (.27)	= 1.2 (.09)	= 1.2 (.09)	= 8.3 (.61)	= .0 (.00)	= 10.0 (.73)
VOR/C	-16.4 (-1.20)	-6.4 (-.47)	-16.7 (-1.22)	-16.7 (-1.22)	.0 (.00)	-16.7 (-1.22)	.0 (.00)
	+ 8.5 (.62)	+ .1 (.01)	+ 7.9 (.58)	+ 7.9 (.58)	+ -1.7 (-.12)	+ 6.7 (.49)	+ .0 (.00)
	= -7.9 (-.58)	= -6.3 (-.46)	= -8.7 (-.64)	= -8.7 (-.64)	= -1.7 (-.12)	=-10.0 (-.73)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ROUTE STRUCTURE BENEFIT: GROUND, WIND AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 41 LAX ORD

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00) + .0 (.00) = .0 (.00)	5.7 (.42) + -4.2 (-.30) = 1.6 (.11)	-1.0 (-.07) + .1 (.01) = -.9 (-.06)	-1.0 (-.07) + .1 (.01) = -.9 (-.06)	13.4 (.98) + -7.2 (-.53) = 6.2 (.45)	-1.0 (-.07) + -1.1 (-.08) = -2.1 (-.15)	13.4 (.98) + -5.6 (-.40) = 7.9 (.57)
SCI/NAFEC	-5.7 (-.42) + 4.2 (.31) = -1.6 (-.11)	.0 (.00) + .0 (.00) = .0 (.00)	-6.7 (-.49) + 4.3 (.31) = -2.4 (-.18)	-6.7 (-.49) + 4.3 (.31) = -2.4 (-.18)	7.7 (.56) + -3.1 (-.22) = 4.6 (.34)	-6.7 (-.49) + 3.0 (.22) = -3.7 (-.27)	7.7 (.56) + -1.4 (-.10) = 6.3 (.46)
FAA/NAFEC	1.0 (.07) + -.1 (-.01) = .9 (.06)	6.7 (.49) + -4.3 (-.31) = 2.4 (.18)	.0 (.00) + .0 (.00) = .0 (.00)	.0 (.00) + .0 (.00) = .0 (.00)	14.4 (1.05) + -7.3 (-.53) = 7.1 (.52)	.0 (.00) + -1.2 (-.09) = -1.2 (-.09)	14.4 (1.05) + -5.7 (-.41) = 8.7 (.64)
SCI/FA/NAFEC	1.0 (.07) + -.1 (-.01) = .9 (.06)	6.7 (.49) + -4.3 (-.31) = 2.4 (.18)	.0 (.00) + .0 (.00) = .0 (.00)	.0 (.00) + .0 (.00) = .0 (.00)	14.4 (1.05) + -7.3 (-.53) = 7.1 (.52)	.0 (.00) + -1.2 (-.09) = -1.2 (-.09)	14.4 (1.05) + -5.7 (-.41) = 8.7 (.64)
VOR/A	-13.4 (-.98) + 7.2 (.53) = -6.2 (-.45)	-7.7 (-.56) + 3.1 (.22) = -4.6 (-.34)	-14.4 (-1.05) + 7.3 (.54) = -7.1 (-.52)	-14.4 (-1.05) + 7.3 (.54) = -7.1 (-.52)	.0 (.00) + .0 (.00) = .0 (.00)	-14.4 (-1.05) + 6.1 (.45) = -8.3 (-.61)	.0 (.00) + 1.7 (.12) = 1.7 (.12)
PRE-PLANNED	1.0 (.07) + 1.1 (.08) = 2.1 (.15)	6.7 (.49) + -3.0 (-.22) = 3.7 (.27)	.0 (.00) + 1.2 (.09) = 1.2 (.09)	.0 (.00) + 1.2 (.09) = 1.2 (.09)	14.4 (1.05) + -6.1 (-.44) = 8.3 (.61)	.0 (.00) + .0 (.00) = .0 (.00)	14.4 (1.05) + -4.4 (-.32) = 10.0 (.73)
VOR/C	-13.4 (-.98) + 5.6 (.41) = -7.9 (-.58)	-7.7 (-.56) + 1.4 (.10) = -6.3 (-.46)	-14.4 (-1.05) + 5.7 (.41) = -8.7 (-.64)	-14.4 (-1.05) + 5.7 (.41) = -8.7 (-.64)	.0 (.00) + -1.7 (-.12) = -1.7 (-.12)	-14.4 (-1.05) + 4.4 (.32) = -10.0 (-.73)	.0 (.00) + .0 (.00) = .0 (.00)

ROUTE STRUCTURE COMPARISONS

PREFERRED ROUTE: GROUND, WIND AND TOTAL BENEFIT

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 51: EWR ORD

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	2.2 (.30)	2.6 (.36)	2.2 (.30)	-1.1 (-.15)	-1.1 (-.15)	-1.1 (-.15)
	+ .0 (.00)	+ 1.4 (.19)	+ .5 (.07)	+ 1.4 (.19)	+ 6.0 (.83)	+ 6.0 (.83)	+ 6.0 (.83)
	= .0 (.00)	= 3.5 (.49)	= 3.2 (.43)	= 3.5 (.49)	= 4.9 (.67)	= 4.9 (.67)	= 4.9 (.67)
SCI/NAFEC	-2.2 (-.30)	.0 (.00)	.5 (.07)	.0 (.00)	-3.3 (-.45)	-3.3 (-.45)	-3.3 (-.45)
	+ -1.4 (-.19)	+ .0 (.00)	+ -.9 (-.12)	+ .0 (.00)	+ 4.6 (.64)	+ 4.6 (.64)	+ 4.6 (.64)
	= -3.5 (-.49)	= .0 (.00)	= -.4 (-.05)	= .0 (.00)	= 1.4 (.19)	= 1.4 (.19)	= 1.4 (.19)
FAA/NAFEC	-2.6 (-.36)	-.5 (-.07)	.0 (.00)	-.5 (-.07)	-3.7 (-.51)	-3.7 (-.51)	-3.7 (-.51)
	+ -.5 (-.07)	+ .9 (.12)	+ .0 (.00)	+ .9 (.12)	+ 5.5 (.75)	+ 5.5 (.75)	+ 5.5 (.75)
	= -3.2 (-.44)	= .4 (.05)	= .0 (.00)	= .4 (.05)	= 1.7 (.24)	= 1.7 (.24)	= 1.7 (.24)
SCI/FA/NAFEC	-2.2 (-.30)	.0 (.00)	.5 (.07)	.0 (.00)	-3.3 (-.45)	-3.3 (-.45)	-3.3 (-.45)
	+ -1.4 (-.19)	+ .0 (.00)	+ -.9 (-.12)	+ .0 (.00)	+ 4.6 (.64)	+ 4.6 (.64)	+ 4.6 (.64)
	= -3.5 (-.49)	= .0 (.00)	= -.4 (-.05)	= .0 (.00)	= 1.4 (.19)	= 1.4 (.19)	= 1.4 (.19)
VOR/A	1.1 (.15)	3.3 (.45)	3.7 (.52)	3.3 (.45)	.0 (.00)	.0 (.00)	.0 (.00)
	+ -6.0 (-.83)	+ -4.6 (-.64)	+ -5.5 (-.76)	+ -4.6 (-.64)	+ .0 (.00)	+ .0 (.00)	+ .0 (.00)
	= -4.9 (-.68)	= -1.4 (-.19)	= -1.7 (-.24)	= -1.4 (-.19)	= .0 (.00)	= .0 (.00)	= .0 (.00)
PRE-PLANNED	1.1 (.15)	3.3 (.45)	3.7 (.52)	3.3 (.45)	.0 (.00)	.0 (.00)	.0 (.00)
	+ -6.0 (-.83)	+ -4.6 (-.64)	+ -5.5 (-.76)	+ -4.6 (-.64)	+ .0 (.00)	+ .0 (.00)	+ .0 (.00)
	= -4.9 (-.68)	= -1.4 (-.19)	= -1.7 (-.24)	= -1.4 (-.19)	= .0 (.00)	= .0 (.00)	= .0 (.00)
VOR/C	1.1 (.15)	3.3 (.45)	3.7 (.52)	3.3 (.45)	.0 (.00)	.0 (.00)	.0 (.00)
	+ -6.0 (-.83)	+ -4.6 (-.64)	+ -5.5 (-.76)	+ -4.6 (-.64)	+ .0 (.00)	+ .0 (.00)	+ .0 (.00)
	= -4.9 (-.68)	= -1.4 (-.19)	= -1.7 (-.24)	= -1.4 (-.19)	= .0 (.00)	= .0 (.00)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ALTERNATE ROUTE BENEFIT: PREFERRED ROUTE, ADDITIONAL ROUTES AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 5: EWR ORD

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	3.5 (.49)	3.2 (.43)	3.5 (.49)	4.9 (.67)	4.9 (.68)	4.9 (.67)
	+ .0 (.00)	+ .8 (.12)	+ 1.9 (.26)	+ .8 (.12)	+ .8 (.11)	+ -5.4 (-.75)	+ 3.0 (.41)
	= .0 (.00)	= 4.4 (.61)	= 5.0 (.69)	= 4.4 (.61)	= 5.7 (.78)	= -.5 (-.07)	= 7.9 (1.08)
SCI/NAFEC	-3.5 (-.49)	.0 (.00)	-.4 (-.05)	.0 (.00)	1.4 (.19)	1.4 (.19)	1.4 (.19)
	+ -.8 (-.12)	+ .0 (.00)	+ 1.0 (.14)	+ .0 (.00)	+ -.1 (-.01)	+ -6.2 (-.87)	+ 2.2 (.30)
	= -4.4 (-.61)	= .0 (.00)	= .6 (.09)	= .0 (.00)	= 1.3 (.18)	= -4.9 (-.68)	= 3.5 (.48)
FAA/NAFEC	-3.2 (-.44)	.4 (.05)	.0 (.00)	.4 (.05)	1.7 (.24)	1.7 (.24)	1.7 (.24)
	+ -1.9 (-.26)	+ -1.0 (-.14)	+ .0 (.00)	+ -1.0 (-.14)	+ -1.1 (-.15)	+ -7.3 (-1.01)	+ 1.1 (.15)
	= -5.0 (-.70)	= -.6 (-.09)	= .0 (.00)	= -.6 (-.09)	= .6 (.09)	= -5.5 (-.77)	= 2.9 (.39)
SCI/FA/NAFEC	-3.5 (-.49)	.0 (.00)	-.4 (-.05)	.0 (.00)	1.4 (.19)	1.4 (.19)	1.4 (.19)
	+ -.8 (-.12)	+ .0 (.00)	+ 1.0 (.14)	+ .0 (.00)	+ -.1 (-.01)	+ -6.2 (-.87)	+ 2.2 (.30)
	= -4.4 (-.61)	= .0 (.00)	= .6 (.09)	= .0 (.00)	= 1.3 (.18)	= -4.9 (-.68)	= 3.5 (.48)
VOR/A	-4.9 (-.68)	-1.4 (-.19)	-1.7 (-.24)	-1.4 (-.19)	.0 (.00)	.0 (.00)	.0 (.00)
	+ -.8 (-.11)	+ .1 (.01)	+ 1.1 (.15)	+ .1 (.01)	+ .0 (.00)	+ -6.2 (-.86)	+ 2.2 (.31)
	= -5.7 (-.79)	= -1.3 (-.18)	= -.6 (-.09)	= -1.3 (-.18)	= .0 (.00)	= -6.2 (-.86)	= 2.2 (.31)
PRE-PLANNED	-4.9 (-.68)	-1.4 (-.19)	-1.7 (-.24)	-1.4 (-.19)	.0 (.00)	.0 (.00)	.0 (.00)
	+ 5.4 (.75)	+ 6.2 (.86)	+ 7.3 (1.00)	+ 6.2 (.86)	+ 6.2 (.85)	+ .0 (.00)	+ 8.4 (1.15)
	= .5 (.07)	= 4.9 (.67)	= 5.5 (.76)	= 4.9 (.67)	= 6.2 (.85)	= .0 (.00)	= 8.4 (1.15)
VOR/C	-4.9 (-.68)	-1.4 (-.19)	-1.7 (-.24)	-1.4 (-.19)	.0 (.00)	.0 (.00)	.0 (.00)
	+ -3.0 (-.42)	+ -2.2 (-.30)	+ -1.1 (-.16)	+ -2.2 (-.30)	+ -2.2 (-.31)	+ -8.4 (-1.17)	+ .0 (.00)
	= -7.9 (-1.10)	= -3.5 (-.48)	= -2.9 (-.40)	= -3.5 (-.48)	= -2.2 (-.31)	= -8.4 (-1.17)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ROUTE STRUCTURE BENEFIT: GROUND, WIND AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 51 EWR ORD

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	2.2 (.30)	2.6 (.36)	2.2 (.30)	-1.1 (-.15)	-1.1 (-.15)	-1.1 (-.15)
	+ .0 (.00)	+ 2.2 (.31)	+ 2.4 (.33)	+ 2.2 (.31)	+ 6.8 (.93)	+ .6 (.09)	+ 9.0 (1.24)
	= .0 (.00)	= 4.4 (.61)	= 5.0 (.69)	= 4.4 (.61)	= 5.7 (.78)	= -.5 (-.07)	= 7.9 (1.08)
SCI/NAFEC	-2.2 (-.30)	.0 (.00)	.5 (.07)	.0 (.00)	-3.3 (-.45)	-3.3 (-.46)	-3.3 (-.45)
	+ -2.2 (-.31)	+ .0 (.00)	+ .2 (.02)	+ .0 (.00)	+ 4.6 (.63)	+ -1.6 (-.22)	+ 6.8 (.93)
	= -4.4 (-.61)	= .0 (.00)	= .6 (.09)	= .0 (.00)	= 1.3 (.18)	= -4.9 (-.68)	= 3.5 (.48)
FAA/NAFEC	-2.6 (-.37)	-.5 (-.07)	.0 (.00)	-.5 (-.07)	-3.7 (-.52)	-3.7 (-.52)	-3.7 (-.52)
	+ -2.4 (-.33)	+ -.2 (-.02)	+ .0 (.00)	+ -.2 (-.02)	+ 4.4 (.61)	+ -1.8 (-.25)	+ 6.6 (.91)
	= -5.0 (-.70)	= -.6 (-.09)	= .0 (.00)	= -.6 (-.09)	= .6 (.09)	= -5.5 (-.77)	= 2.9 (.39)
SCI/FA/NAFEC	-2.2 (-.30)	.0 (.00)	.5 (.07)	.0 (.00)	-3.3 (-.45)	-3.3 (-.46)	-3.3 (-.45)
	+ -2.2 (-.31)	+ .0 (.00)	+ .2 (.02)	+ .0 (.00)	+ 4.6 (.63)	+ -1.6 (-.22)	+ 6.8 (.93)
	= -4.4 (-.61)	= .0 (.00)	= .6 (.09)	= .0 (.00)	= 1.3 (.18)	= -4.9 (-.68)	= 3.5 (.48)
VOR/A	1.1 (.15)	3.3 (.45)	3.7 (.52)	3.3 (.45)	.0 (.00)	.0 (.00)	.0 (.00)
	+ -6.8 (-.94)	+ -4.6 (-.63)	+ -4.4 (-.61)	+ -4.6 (-.63)	+ .0 (.00)	+ -6.2 (-.86)	+ 2.2 (.31)
	= -5.7 (-.79)	= -1.3 (-.18)	= -.6 (-.09)	= -1.3 (-.18)	= .0 (.00)	= -6.2 (-.86)	= 2.2 (.31)
PRE-PLANNED	1.1 (.15)	3.3 (.45)	3.7 (.52)	3.3 (.45)	.0 (.00)	.0 (.00)	.0 (.00)
	+ -.6 (-.09)	+ 1.6 (.22)	+ 1.8 (.24)	+ 1.6 (.22)	+ 6.2 (.85)	+ .0 (.00)	+ 8.4 (1.15)
	= .5 (.07)	= 4.9 (.67)	= 5.5 (.76)	= 4.9 (.67)	= 6.2 (.85)	= .0 (.00)	= 8.4 (1.15)
VOR/C	1.1 (.15)	3.3 (.45)	3.7 (.52)	3.3 (.45)	.0 (.00)	.0 (.00)	.0 (.00)
	+ -9.0 (-1.25)	+ -6.8 (-.94)	+ -6.6 (-.91)	+ -6.8 (-.94)	+ -2.2 (-.31)	+ -8.4 (-1.17)	+ .0 (.00)
	= -7.9 (-1.10)	= -3.5 (-.48)	= -2.9 (-.40)	= -3.5 (-.48)	= -2.2 (-.31)	= -8.4 (-1.17)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

PREFERRED ROUTE: GROUND, WIND AND TOTAL BENEFIT

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 61 ORD EWR

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	.7 (.13)	.0 (.00)	.0 (.00)	.0 (.00)	-1.1 (-.19)	.0 (.00)
	+ .0 (.00)	+ -1.0 (-.17)	+ .2 (.04)	+ .2 (.04)	+ .2 (.04)	+ .6 (.10)	+ .2 (.04)
	= .0 (.00)	= -.3 (-.04)	= .2 (.04)	= .2 (.04)	= .2 (.04)	= -.5 (-.09)	= .2 (.04)
SCI/NAFEC	-.7 (-.13)	.0 (.00)	-.7 (-.13)	-.7 (-.13)	-.7 (-.13)	-1.8 (-.32)	-.7 (-.13)
	+ 1.0 (.17)	+ .0 (.00)	+ 1.2 (.21)	+ 1.2 (.21)	+ 1.2 (.21)	+ 1.6 (.27)	+ 1.2 (.21)
	= .3 (.04)	= .0 (.00)	= .5 (.08)	= .5 (.08)	= .5 (.08)	= -.3 (-.05)	= .5 (.08)
FAA/NAFEC	.0 (.00)	.7 (.13)	.0 (.00)	.0 (.00)	.0 (.00)	-1.1 (-.19)	.0 (.00)
	+ -.2 (-.04)	+ -1.2 (-.21)	+ .0 (.00)	+ .0 (.00)	+ .0 (.00)	+ .3 (.06)	+ .0 (.00)
	= -.2 (-.04)	= -.5 (-.08)	= .0 (.00)	= .0 (.00)	= .0 (.00)	= -.8 (-.13)	= .0 (.00)
SCI/FA/NAFEC	.0 (.00)	.7 (.13)	.0 (.00)	.0 (.00)	.0 (.00)	-1.1 (-.19)	.0 (.00)
	+ -.2 (-.04)	+ -1.2 (-.21)	+ .0 (.00)	+ .0 (.00)	+ .0 (.00)	+ .3 (.06)	+ .0 (.00)
	= -.2 (-.04)	= -.5 (-.08)	= .0 (.00)	= .0 (.00)	= .0 (.00)	= -.8 (-.13)	= .0 (.00)
VOR/A	.0 (.00)	.7 (.13)	.0 (.00)	.0 (.00)	.0 (.00)	-1.1 (-.19)	.0 (.00)
	+ -.2 (-.04)	+ -1.2 (-.21)	+ .0 (.00)	+ .0 (.00)	+ .0 (.00)	+ .3 (.06)	+ .0 (.00)
	= -.2 (-.04)	= -.5 (-.08)	= .0 (.00)	= .0 (.00)	= .0 (.00)	= -.8 (-.13)	= .0 (.00)
PRE-PLANNED	1.1 (.19)	1.8 (.32)	1.1 (.19)	1.1 (.19)	1.1 (.19)	.0 (.00)	1.1 (.19)
	+ -.6 (-.10)	+ -1.6 (-.27)	+ -.3 (-.06)	+ -.3 (-.06)	+ -.3 (-.06)	+ .0 (.00)	+ -.3 (-.06)
	= .5 (.09)	= .3 (.05)	= .8 (.13)	= .8 (.13)	= .8 (.13)	= .0 (.00)	= .8 (.13)
VOR/C	.0 (.00)	.7 (.13)	.0 (.00)	.0 (.00)	.0 (.00)	-1.1 (-.19)	.0 (.00)
	+ -.2 (-.04)	+ -1.2 (-.21)	+ .0 (.00)	+ .0 (.00)	+ .0 (.00)	+ .3 (.06)	+ .0 (.00)
	= -.2 (-.04)	= -.5 (-.08)	= .0 (.00)	= .0 (.00)	= .0 (.00)	= -.8 (-.13)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ALTERNATE ROUTE BENEFIT: PREFERRED ROUTE, ADDITIONAL ROUTES AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 61 ORD EWR

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	-.3 (-.04)	.2 (.04)	.2 (.04)	.2 (.04)	-.5 (-.09)	.2 (.04)
	+ .0 (.00)	+ .0 (.00)	+ -1.6 (-.28)	+ -1.6 (-.28)	+ .0 (.00)	+ -1.2 (-.21)	+ .0 (.00)
	= .0 (.00)	= -.3 (-.04)	= -1.4 (-.24)	= -1.4 (-.24)	= .2 (.04)	= -1.7 (-.30)	= .2 (.04)
SCI/NAFEC	.3 (.04)	.0 (.00)	.5 (.08)	.5 (.08)	.5 (.08)	-.3 (-.05)	.5 (.08)
	+ .0 (.00)	+ .0 (.00)	+ -1.6 (-.28)	+ -1.6 (-.28)	+ .0 (.00)	+ -1.2 (-.21)	+ .0 (.00)
	= .3 (.04)	= .0 (.00)	= -1.1 (-.20)	= -1.1 (-.20)	= .5 (.08)	= -1.5 (-.26)	= .5 (.08)
FAA/NAFEC	-.2 (-.04)	-.5 (-.08)	.0 (.00)	.0 (.00)	.0 (.00)	-.8 (-.13)	.0 (.00)
	+ 1.6 (.28)	+ 1.6 (.28)	+ .0 (.00)	+ .0 (.00)	+ 1.6 (.28)	+ .4 (.07)	+ 1.6 (.28)
	= 1.4 (.24)	= 1.1 (.20)	= .0 (.00)	= .0 (.00)	= 1.6 (.28)	= -.4 (-.06)	= 1.6 (.28)
SCI/FA/NAFEC	-.2 (-.04)	-.5 (-.08)	.0 (.00)	.0 (.00)	.0 (.00)	-.8 (-.13)	.0 (.00)
	+ 1.6 (.28)	+ 1.6 (.28)	+ .0 (.00)	+ .0 (.00)	+ 1.6 (.28)	+ .4 (.07)	+ 1.6 (.28)
	= 1.4 (.24)	= 1.1 (.20)	= .0 (.00)	= .0 (.00)	= 1.6 (.28)	= -.4 (-.06)	= 1.6 (.28)
VOR/A	-.2 (-.04)	-.5 (-.08)	.0 (.00)	.0 (.00)	.0 (.00)	-.8 (-.13)	.0 (.00)
	+ .0 (.00)	+ .0 (.00)	+ -1.6 (-.28)	+ -1.6 (-.28)	+ .0 (.00)	+ -1.2 (-.21)	+ .0 (.00)
	= -.2 (-.04)	= -.5 (-.08)	= -1.6 (-.28)	= -1.6 (-.28)	= .0 (.00)	= -2.0 (-.34)	= .0 (.00)
PRE-PLANNED	.5 (.09)	.3 (.05)	.8 (.13)	.8 (.13)	.8 (.13)	.0 (.00)	.8 (.13)
	+ 1.2 (.21)	+ 1.2 (.21)	+ -.4 (-.07)	+ -.4 (-.07)	+ 1.2 (.21)	+ .0 (.00)	+ 1.2 (.21)
	= 1.7 (.30)	= 1.5 (.26)	= .4 (.06)	= .4 (.06)	= 2.0 (.34)	= .0 (.00)	= 2.0 (.34)
VOR/C	-.2 (-.04)	-.5 (-.08)	.0 (.00)	.0 (.00)	.0 (.00)	-.8 (-.13)	.0 (.00)
	+ .0 (.00)	+ .0 (.00)	+ -1.6 (-.28)	+ -1.6 (-.28)	+ .0 (.00)	+ -1.2 (-.21)	+ .0 (.00)
	= -.2 (-.04)	= -.5 (-.08)	= -1.6 (-.28)	= -1.6 (-.28)	= .0 (.00)	= -2.0 (-.34)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ROUTE STRUCTURE BENEFIT: GROUND, WIND AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 61 ORD EWR

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	.7 (.13)	.0 (.00)	.0 (.00)	.0 (.00)	-1.1 (-.19)	.0 (.00)
	+ .0 (.00)	+ -1.0 (-.17)	+ -1.4 (-.24)	+ -1.4 (-.24)	+ .2 (.04)	+ -.6 (-.11)	+ .2 (.04)
	= .0 (.00)	= -.3 (-.04)	= -1.4 (-.24)	= -1.4 (-.24)	= .2 (.04)	= -1.7 (-.30)	= .2 (.04)
SCI/NAFEC	-.7 (-.13)	.0 (.00)	-.7 (-.13)	-.7 (-.13)	-.7 (-.13)	-1.8 (-.32)	-.7 (-.13)
	+ 1.0 (.17)	+ .0 (.00)	+ -.4 (-.07)	+ -.4 (-.07)	+ 1.2 (.21)	+ .4 (.06)	+ 1.2 (.21)
	= .3 (.04)	= .0 (.00)	= -1.1 (-.20)	= -1.1 (-.20)	= .5 (.08)	= -1.5 (-.26)	= .5 (.08)
FAA/NAFEC	.0 (.00)	.7 (.13)	.0 (.00)	.0 (.00)	.0 (.00)	-1.1 (-.19)	.0 (.00)
	+ 1.4 (.24)	+ .4 (.07)	+ .0 (.00)	+ .0 (.00)	+ 1.6 (.28)	+ .7 (.13)	+ 1.6 (.28)
	= 1.4 (.24)	= 1.1 (.20)	= .0 (.00)	= .0 (.00)	= 1.6 (.28)	= -.4 (-.06)	= 1.6 (.28)
SCI/FA/NAFEC	.0 (.00)	.7 (.13)	.0 (.00)	.0 (.00)	.0 (.00)	-1.1 (-.19)	.0 (.00)
	+ 1.4 (.24)	+ .4 (.07)	+ .0 (.00)	+ .0 (.00)	+ 1.6 (.28)	+ .7 (.13)	+ 1.6 (.28)
	= 1.4 (.24)	= 1.1 (.20)	= .0 (.00)	= .0 (.00)	= 1.6 (.28)	= -.4 (-.06)	= 1.6 (.28)
VOR/A	.0 (.00)	.7 (.13)	.0 (.00)	.0 (.00)	.0 (.00)	-1.1 (-.19)	.0 (.00)
	+ -.2 (-.04)	+ -1.2 (-.21)	+ -1.6 (-.28)	+ -1.6 (-.28)	+ .0 (.00)	+ -.9 (-.15)	+ .0 (.00)
	= -.2 (-.04)	= -.5 (-.08)	= -1.6 (-.28)	= -1.6 (-.28)	= .0 (.00)	= -2.0 (-.34)	= .0 (.00)
PRE-PLANNED	1.1 (.19)	1.8 (.32)	1.1 (.19)	1.1 (.19)	1.1 (.19)	.0 (.00)	1.1 (.19)
	+ .6 (.11)	+ -.4 (-.06)	+ -.7 (-.13)	+ -.7 (-.13)	+ .9 (.15)	+ .0 (.00)	+ .9 (.15)
	= 1.7 (.30)	= 1.5 (.26)	= .4 (.06)	= .4 (.06)	= 2.0 (.34)	= .0 (.00)	= 2.0 (.34)
VOR/C	.0 (.00)	.7 (.13)	.0 (.00)	.0 (.00)	.0 (.00)	-1.1 (-.19)	.0 (.00)
	+ -.2 (-.04)	+ -1.2 (-.21)	+ -1.6 (-.28)	+ -1.6 (-.28)	+ .0 (.00)	+ -.9 (-.15)	+ .0 (.00)
	= -.2 (-.04)	= -.5 (-.08)	= -1.6 (-.28)	= -1.6 (-.28)	= .0 (.00)	= -2.0 (-.34)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

PREFERRED ROUTE: GROUND, WIND AND TOTAL BENEFIT

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 7: IAD LAX

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	-1.8 (-.08)	13.1 (.57)	13.1 (.57)	1.0 (.04)	-4.4 (-.19)	1.0 (.04)
	+ .0 (.00)	+ -1.0 (-.04)	+-49.6 (-2.16)	+-49.6 (-2.16)	+-13.9 (-.60)	+-19.7 (-.85)	+-13.9 (-.60)
	= .0 (.00)	= -2.7 (-.12)	=-36.5 (-1.59)	=-36.5 (-1.59)	=-12.9 (-.56)	=-24.1 (-1.04)	=-12.9 (-.56)
SCI/NAFEC	1.8 (.08)	.0 (.00)	14.9 (.65)	14.9 (.65)	2.8 (.12)	-2.7 (-.12)	2.8 (.12)
	+ 1.0 (.04)	+ .0 (.00)	+-48.6 (-2.11)	+-48.6 (-2.11)	+-12.9 (-.56)	+-18.7 (-.81)	+-12.9 (-.56)
	= 2.7 (.12)	= .0 (.00)	=-33.7 (-1.47)	=-33.7 (-1.47)	=-10.2 (-.44)	=-21.3 (-.92)	=-10.2 (-.44)
FAA/NAFEC	-13.1 (-.56)	-14.9 (-.64)	.0 (.00)	.0 (.00)	-12.2 (-.52)	-17.6 (-.76)	-12.2 (-.52)
	+ 49.6 (2.12)	+ 48.6 (2.08)	+ .0 (.00)	+ .0 (.00)	+ 35.7 (1.54)	+ 30.0 (1.30)	+ 35.7 (1.54)
	= 36.5 (1.56)	= 33.7 (1.45)	= .0 (.00)	= .0 (.00)	= 23.6 (1.01)	= 12.4 (.54)	= 23.6 (1.01)
SCI/FA/NAFEC	-13.1 (-.56)	-14.9 (-.64)	.0 (.00)	.0 (.00)	-12.2 (-.52)	-17.6 (-.76)	-12.2 (-.52)
	+ 49.6 (2.12)	+ 48.6 (2.08)	+ .0 (.00)	+ .0 (.00)	+ 35.7 (1.54)	+ 30.0 (1.30)	+ 35.7 (1.54)
	= 36.5 (1.56)	= 33.7 (1.45)	= .0 (.00)	= .0 (.00)	= 23.6 (1.01)	= 12.4 (.54)	= 23.6 (1.01)
VOR/A	-1.0 (-.04)	-2.8 (-.12)	12.2 (.53)	12.2 (.53)	.0 (.00)	-5.4 (-.23)	.0 (.00)
	+ 13.9 (.60)	+ 12.9 (.55)	+-35.7 (-1.55)	+-35.7 (-1.55)	+ .0 (.00)	+ -5.7 (-.25)	+ .0 (.00)
	= 12.9 (.55)	= 10.2 (.44)	=-23.6 (-1.02)	=-23.6 (-1.02)	= .0 (.00)	=-11.2 (-.48)	= .0 (.00)
PRE-PLANNED	4.4 (.19)	2.7 (.11)	17.6 (.76)	17.6 (.76)	5.4 (.23)	.0 (.00)	5.4 (.23)
	+ 19.7 (.84)	+ 18.7 (.80)	+-30.0 (-1.30)	+-30.0 (-1.30)	+ 5.7 (.25)	+ .0 (.00)	+ 5.7 (.25)
	= 24.1 (1.03)	= 21.3 (.91)	=-12.4 (-.54)	=-12.4 (-.54)	= 11.2 (.48)	= .0 (.00)	= 11.2 (.48)
VOR/C	-1.0 (-.04)	-2.8 (-.12)	12.2 (.53)	12.2 (.53)	.0 (.00)	-5.4 (-.23)	.0 (.00)
	+ 13.9 (.60)	+ 12.9 (.55)	+-35.7 (-1.55)	+-35.7 (-1.55)	+ .0 (.00)	+ -5.7 (-.25)	+ .0 (.00)
	= 12.9 (.55)	= 10.2 (.44)	=-23.6 (-1.02)	=-23.6 (-1.02)	= .0 (.00)	=-11.2 (-.48)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ALTERNATE ROUTE BENEFIT: PREFERRED ROUTE, ADDITIONAL ROUTES AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 7: IAD LAX

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	-2.7 (-.12)	-36.5 (-1.59)	-36.5 (-1.59)	-12.9 (-.56)	-24.1 (-1.06)	-12.9 (-.56)
	+ .0 (.00)	+ 5.5 (.24)	+ 37.5 (1.64)	+ 37.5 (1.64)	+ 28.9 (1.26)	+ 11.6 (.51)	+ 36.2 (1.56)
	= .0 (.00)	= 2.8 (.12)	= 1.1 (.05)	= 1.1 (.05)	= 16.0 (.69)	=-12.5 (-.55)	= 23.2 (1.01)
SCI/NAFEC	2.7 (.12)	.0 (.00)	-33.7 (-1.47)	-33.7 (-1.47)	-10.2 (-.44)	-21.3 (-.94)	-10.2 (-.44)
	+ -5.5 (-.24)	+ .0 (.00)	+ 32.0 (1.40)	+ 32.0 (1.40)	+ 23.4 (1.02)	+ 6.0 (.26)	+ 30.6 (1.32)
	= -2.8 (-.12)	= .0 (.00)	= -1.7 (-.08)	= -1.7 (-.08)	= 13.2 (.57)	=-15.3 (-.67)	= 20.4 (.88)
FAA/NAFEC	36.5 (1.59)	33.7 (1.47)	.0 (.00)	.0 (.00)	23.6 (1.02)	12.4 (.55)	23.6 (1.02)
	+-37.5 (-1.64)	+-32.0 (-1.40)	+ .0 (.00)	+ .0 (.00)	+ -8.6 (-.37)	+-26.0 (-1.14)	+ -1.4 (-.06)
	= -1.1 (-.05)	= 1.7 (.08)	= .0 (.00)	= .0 (.00)	= 14.9 (.65)	=-13.6 (-.60)	= 22.2 (.96)
SCI/FA/NAFEC	36.5 (1.59)	33.7 (1.47)	.0 (.00)	.0 (.00)	23.6 (1.02)	12.4 (.55)	23.6 (1.02)
	+-37.5 (-1.64)	+-32.0 (-1.40)	+ .0 (.00)	+ .0 (.00)	+ -8.6 (-.37)	+-26.0 (-1.14)	+ -1.4 (-.06)
	= -1.1 (-.05)	= 1.7 (.08)	= .0 (.00)	= .0 (.00)	= 14.9 (.65)	=-13.6 (-.60)	= 22.2 (.96)
VOR/A	12.9 (.56)	10.2 (.44)	-23.6 (-1.03)	-23.6 (-1.03)	.0 (.00)	-11.2 (-.49)	.0 (.00)
	+-28.9 (-1.26)	+-23.4 (-1.02)	+ 8.6 (.38)	+ 8.6 (.38)	+ .0 (.00)	+-17.4 (-.76)	+ 7.2 (.31)
	=-16.0 (-.70)	=-13.2 (-.58)	=-14.9 (-.65)	=-14.9 (-.65)	= .0 (.00)	=-28.5 (-1.25)	= 7.2 (.31)
PRE-PLANNED	24.1 (1.05)	21.3 (.93)	-12.4 (-.54)	-12.4 (-.54)	11.2 (.48)	.0 (.00)	11.2 (.48)
	+-11.6 (-.51)	+ -6.0 (-.26)	+ 26.0 (1.13)	+ 26.0 (1.13)	+ 17.4 (.75)	+ .0 (.00)	+ 24.6 (1.06)
	= 12.5 (.55)	= 15.3 (.67)	= 13.6 (.59)	= 13.6 (.59)	= 28.5 (1.24)	= .0 (.00)	= 35.7 (1.55)
VOR/C	12.9 (.56)	10.2 (.44)	-23.6 (-1.03)	-23.6 (-1.03)	.0 (.00)	-11.2 (-.49)	.0 (.00)
	+-36.2 (-1.58)	+-30.6 (-1.34)	+ 1.4 (.06)	+ 1.4 (.06)	+ -7.2 (-.31)	+-24.6 (-1.08)	+ .0 (.00)
	=-23.2 (-1.02)	=-20.4 (-.89)	=-22.2 (-.97)	=-22.2 (-.97)	= -7.2 (-.31)	=-35.7 (-1.57)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ROUTE STRUCTURE BENEFIT: GROUND, WIND AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 71 IAD LAX

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	-1.8 (-.08)	13.1 (.57)	13.1 (.57)	1.0 (.04)	-4.4 (-.19)	1.0 (.04)
	+ .0 (.00)	+ 4.5 (.20)	+-12.1 (-.53)	+-12.1 (-.53)	+ 15.0 (.65)	+ -8.1 (-.36)	+ 22.2 (.96)
	= .0 (.00)	= 2.8 (.12)	= 1.1 (.05)	= 1.1 (.05)	= 16.0 (.69)	=-12.5 (-.55)	= 23.2 (1.01)
SCI/NAFEC	1.8 (.08)	.0 (.00)	14.9 (.65)	14.9 (.65)	2.8 (.12)	-2.7 (-.12)	2.8 (.12)
	+ -4.5 (-.20)	+ .0 (.00)	+-16.6 (-.73)	+-16.6 (-.73)	+ 10.5 (.45)	+-12.6 (-.56)	+ 17.7 (.77)
	= -2.8 (-.12)	= .0 (.00)	= -1.7 (-.08)	= -1.7 (-.08)	= 13.2 (.57)	=-15.3 (-.67)	= 20.4 (.88)
FAA/NAFEC	-13.1 (-.57)	-14.9 (-.65)	.0 (.00)	.0 (.00)	-12.2 (-.53)	-17.6 (-.77)	-12.2 (-.53)
	+ 12.1 (.53)	+ 16.6 (.73)	+ .0 (.00)	+ .0 (.00)	+ 27.1 (1.18)	+ 4.0 (.18)	+ 34.3 (1.49)
	= -1.1 (-.05)	= 1.7 (.08)	= .0 (.00)	= .0 (.00)	= 14.9 (.65)	=-13.6 (-.60)	= 22.2 (.96)
SCT/FA/NAFEC	-13.1 (-.57)	-14.9 (-.65)	.0 (.00)	.0 (.00)	-12.2 (-.53)	-17.6 (-.77)	-12.2 (-.53)
	+ 12.1 (.53)	+ 16.6 (.73)	+ .0 (.00)	+ .0 (.00)	+ 27.1 (1.18)	+ 4.0 (.18)	+ 34.3 (1.49)
	= -1.1 (-.05)	= 1.7 (.08)	= .0 (.00)	= .0 (.00)	= 14.9 (.65)	=-13.6 (-.60)	= 22.2 (.96)
VOR/A	-1.0 (-.04)	-2.8 (-.12)	12.2 (.53)	12.2 (.53)	.0 (.00)	-5.4 (-.24)	.0 (.00)
	+-15.0 (-.66)	+-10.5 (-.46)	+-27.1 (-1.18)	+-27.1 (-1.18)	+ .0 (.00)	+-23.1 (-1.02)	+ 7.2 (.31)
	=-16.0 (-.70)	=-13.2 (-.58)	=-14.9 (-.65)	=-14.9 (-.65)	= .0 (.00)	=-28.5 (-1.25)	= 7.2 (.31)
PRE-PLANNED	4.4 (.19)	2.7 (.12)	17.6 (.77)	17.6 (.77)	5.4 (.23)	.0 (.00)	5.4 (.23)
	+ 8.1 (.35)	+ 12.6 (.55)	+ -4.0 (-.17)	+ -4.0 (-.17)	+ 23.1 (1.00)	+ .0 (.00)	+ 30.3 (1.31)
	= 12.5 (.55)	= 15.3 (.67)	= 13.6 (.59)	= 13.6 (.59)	= 28.5 (1.24)	= .0 (.00)	= 35.7 (1.55)
VOR/C	-1.0 (-.04)	-2.8 (-.12)	12.2 (.53)	12.2 (.53)	.0 (.00)	-5.4 (-.24)	.0 (.00)
	+-22.2 (-.97)	+-17.7 (-.77)	+-34.3 (-1.50)	+-34.3 (-1.50)	+ -7.2 (-.31)	+-30.3 (-1.33)	+ .0 (.00)
	=-23.2 (-1.02)	=-20.4 (-.89)	=-22.2 (-.97)	=-22.2 (-.97)	= -7.2 (-.31)	=-35.7 (-1.57)	= .0 (.00)

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ROUTE STRUCTURE COMPARISONS

PREFERRED ROUTE: GROUND, WIND AND TOTAL BENEFIT

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 81 LAX IAD

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	.8 (.05)	7.3 (.41)	.8 (.05)	11.9 (.67)	.0 (.00)	11.9 (.67)
	+ .0 (.00)	+ -4.7 (-.26)	+ -1.5 (-.08)	+ -4.7 (-.26)	+ -4.9 (-.28)	+ .0 (.00)	+ -4.9 (-.28)
	= .0 (.00)	= -3.8 (-.22)	= 5.9 (.33)	= -3.8 (-.22)	= 6.9 (.39)	= .0 (.00)	= 6.9 (.39)
SCI/NAFEC	-.8 (-.05)	.0 (.00)	6.5 (.37)	.0 (.00)	11.0 (.62)	-.8 (-.05)	11.0 (.62)
	+ 4.7 (.26)	+ .0 (.00)	+ 3.2 (.18)	+ .0 (.00)	+ -.3 (-.02)	+ 4.7 (.26)	+ -.3 (-.02)
	= 3.8 (.22)	= .0 (.00)	= 9.7 (.54)	= .0 (.00)	= 10.8 (.60)	= 3.8 (.22)	= 10.8 (.60)
FAA/NAFEC	-7.3 (-.41)	-6.5 (-.37)	.0 (.00)	-6.5 (-.37)	4.5 (.25)	-7.3 (-.41)	4.5 (.25)
	+ 1.5 (.08)	+ -3.2 (-.18)	+ .0 (.00)	+ -3.2 (-.18)	+ -3.5 (-.19)	+ 1.5 (.08)	+ -3.5 (-.19)
	= -5.9 (-.33)	= -9.7 (-.55)	= .0 (.00)	= -9.7 (-.55)	= 1.1 (.06)	= -5.9 (-.33)	= 1.1 (.06)
SCI/FA/NAFEC	-.8 (-.05)	.0 (.00)	6.5 (.37)	.0 (.00)	11.0 (.62)	-.8 (-.05)	11.0 (.62)
	+ 4.7 (.26)	+ .0 (.00)	+ 3.2 (.18)	+ .0 (.00)	+ -.3 (-.02)	+ 4.7 (.26)	+ -.3 (-.02)
	= 3.8 (.22)	= .0 (.00)	= 9.7 (.54)	= .0 (.00)	= 10.8 (.60)	= 3.8 (.22)	= 10.8 (.60)
VOR/A	-11.9 (-.67)	-11.0 (-.62)	-4.5 (-.25)	-11.0 (-.62)	.0 (.00)	-11.9 (-.67)	.0 (.00)
	+ 4.9 (.28)	+ .3 (.02)	+ 3.5 (.19)	+ .3 (.02)	+ .0 (.00)	+ 4.9 (.28)	+ .0 (.00)
	= -6.9 (-.39)	= -10.8 (-.61)	= -1.1 (-.06)	= -10.8 (-.61)	= .0 (.00)	= -6.9 (-.39)	= .0 (.00)
PRE-PLANNED	.0 (.00)	.8 (.05)	7.3 (.41)	.8 (.05)	11.9 (.67)	.0 (.00)	11.9 (.67)
	+ .0 (.00)	+ -4.7 (-.26)	+ -1.5 (-.08)	+ -4.7 (-.26)	+ -4.9 (-.28)	+ .0 (.00)	+ -4.9 (-.28)
	= .0 (.00)	= -3.8 (-.22)	= 5.9 (.33)	= -3.8 (-.22)	= 6.9 (.39)	= .0 (.00)	= 6.9 (.39)
VOR/C	-11.9 (-.67)	-11.0 (-.62)	-4.5 (-.25)	-11.0 (-.62)	.0 (.00)	-11.9 (-.67)	.0 (.00)
	+ 4.9 (.28)	+ .3 (.02)	+ 3.5 (.19)	+ .3 (.02)	+ .0 (.00)	+ 4.9 (.28)	+ .0 (.00)
	= -6.9 (-.39)	= -10.8 (-.61)	= -1.1 (-.06)	= -10.8 (-.61)	= .0 (.00)	= -6.9 (-.39)	= .0 (.00)

AD-A039 225 SYSTEMS CONTROL INC PALO ALTO CALIF F/G 17/7

IMPLEMENTATION OF AREA NAVIGATION IN THE NATIONAL AIRSPACE SYST--ETC(U)

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AD A039225

ROUTE STRUCTURE COMPARISONS

ALTERNATE ROUTE BENEFIT: PREFERRED ROUTE, ADDITIONAL ROUTES AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 81 LAX IAD

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	-3.8 (-.22)	5.9 (.33)	-3.8 (-.22)	6.9 (.39)	.0 (.00)	6.9 (.39)
	+ .0 (.00)	+ 1.4 (.08)	+ -1.1 (-.06)	+ 1.4 (.08)	+ .9 (.05)	+ -5.3 (-.30)	+ .9 (.05)
	= .0 (.00)	= -2.4 (-.14)	= 4.8 (.27)	= -2.4 (-.14)	= 7.8 (.44)	= -5.3 (-.30)	= 7.8 (.44)
SCI/NAFEC	3.8 (.22)	.0 (.00)	9.7 (.55)	.0 (.00)	10.8 (.60)	3.8 (.22)	10.8 (.60)
	+ -1.4 (-.08)	+ .0 (.00)	+ -2.5 (-.14)	+ .0 (.00)	+ -.5 (-.03)	+ -6.7 (-.38)	+ -.5 (-.03)
	= 2.4 (.14)	= .0 (.00)	= 7.2 (.40)	= .0 (.00)	= 10.2 (.57)	= -2.9 (-.16)	= 10.2 (.57)
FAA/NAFEC	-5.9 (-.33)	-9.7 (-.55)	.0 (.00)	-9.7 (-.55)	1.1 (.06)	-5.9 (-.33)	1.1 (.06)
	+ 1.1 (.06)	+ 2.5 (.14)	+ .0 (.00)	+ 2.5 (.14)	+ 2.0 (.11)	+ -4.2 (-.24)	+ 2.0 (.11)
	= -4.8 (-.27)	= -7.2 (-.41)	= .0 (.00)	= -7.2 (-.41)	= 3.1 (.17)	=-10.1 (-.57)	= 3.1 (.17)
SCI/FA/NAFEC	3.8 (.22)	.0 (.00)	9.7 (.55)	.0 (.00)	10.8 (.60)	3.8 (.22)	10.8 (.60)
	+ -1.4 (-.08)	+ .0 (.00)	+ -2.5 (-.14)	+ .0 (.00)	+ -.5 (-.03)	+ -6.7 (-.38)	+ -.5 (-.03)
	= 2.4 (.14)	= .0 (.00)	= 7.2 (.40)	= .0 (.00)	= 10.2 (.57)	= -2.9 (-.16)	= 10.2 (.57)
VOR/A	-6.9 (-.39)	-10.8 (-.61)	-1.1 (-.06)	-10.8 (-.61)	.0 (.00)	-6.9 (-.39)	.0 (.00)
	+ -.9 (-.05)	+ .5 (.03)	+ -2.0 (-.11)	+ .5 (.03)	+ .0 (.00)	+ -6.2 (-.35)	+ .0 (.00)
	= -7.8 (-.44)	=-10.2 (-.58)	= -3.1 (-.17)	=-10.2 (-.58)	= .0 (.00)	=-13.1 (-.74)	= .0 (.00)
PRE-PLANNED	.0 (.00)	-3.8 (-.22)	5.9 (.33)	-3.8 (-.22)	6.9 (.39)	.0 (.00)	6.9 (.39)
	+ 5.3 (.30)	+ 6.7 (.38)	+ 4.2 (.24)	+ 6.7 (.38)	+ 6.2 (.35)	+ .0 (.00)	+ 6.2 (.35)
	= 5.3 (.30)	= 2.9 (.16)	= 10.1 (.57)	= 2.9 (.16)	= 13.1 (.74)	= .0 (.00)	= 13.1 (.74)
VOR/C	-6.9 (-.39)	-10.8 (-.61)	-1.1 (-.06)	-10.8 (-.61)	.0 (.00)	-6.9 (-.39)	.0 (.00)
	+ -.9 (-.05)	+ .5 (.03)	+ -2.0 (-.11)	+ .5 (.03)	+ .0 (.00)	+ -6.2 (-.35)	+ .0 (.00)
	= -7.8 (-.44)	=-10.2 (-.58)	= -3.1 (-.17)	=-10.2 (-.58)	= .0 (.00)	=-13.1 (-.74)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ROUTE STRUCTURE BENEFIT: GROUND, WIND AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 8: LAX IAD

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	.8 (.05)	7.3 (.41)	.8 (.05)	11.9 (.67)	.0 (.00)	11.9 (.67)
	+ .0 (.00)	+ -3.2 (-.18)	+ -2.6 (-.14)	+ -3.2 (-.18)	+ -4.0 (-.23)	+ -5.3 (-.30)	+ -4.0 (-.23)
	= .0 (.00)	= -2.4 (-.14)	= 4.8 (.27)	= -2.4 (-.14)	= 7.8 (.44)	= -5.3 (-.30)	= 7.8 (.44)
SCI/NAFEC	-.8 (-.05)	.0 (.00)	6.5 (.37)	.0 (.00)	11.0 (.62)	-.8 (-.05)	11.0 (.62)
	+ 3.2 (.18)	+ .0 (.00)	+ .7 (.04)	+ .0 (.00)	+ -.8 (-.05)	+ -2.1 (-.12)	+ -.8 (-.05)
	= 2.4 (.14)	= .0 (.00)	= 7.2 (.40)	= .0 (.00)	= 10.2 (.57)	= -2.9 (-.16)	= 10.2 (.57)
FAA/NAFEC	-7.3 (-.41)	-6.5 (-.37)	.0 (.00)	-6.5 (-.37)	4.5 (.25)	-7.3 (-.42)	4.5 (.25)
	+ 2.6 (.15)	+ -.7 (-.04)	+ .0 (.00)	+ -.7 (-.04)	+ -1.5 (-.08)	+ -2.7 (-.15)	+ -1.5 (-.08)
	= -4.8 (-.27)	= -7.2 (-.41)	= .0 (.00)	= -7.2 (-.41)	= 3.1 (.17)	=-10.1 (-.57)	= 3.1 (.17)
SCI/FA/NAFEC	-.8 (-.05)	.0 (.00)	6.5 (.37)	.0 (.00)	11.0 (.62)	-.8 (-.05)	11.0 (.62)
	+ 3.2 (.18)	+ .0 (.00)	+ .7 (.04)	+ .0 (.00)	+ -.8 (-.05)	+ -2.1 (-.12)	+ -.8 (-.05)
	= 2.4 (.14)	= .0 (.00)	= 7.2 (.40)	= .0 (.00)	= 10.2 (.57)	= -2.9 (-.16)	= 10.2 (.57)
VOR/A	-11.9 (-.67)	-11.0 (-.62)	-4.5 (-.25)	-11.0 (-.62)	.0 (.00)	-11.9 (-.67)	.0 (.00)
	+ 4.0 (.23)	+ .8 (.05)	+ 1.5 (.08)	+ .8 (.05)	+ .0 (.00)	+ -1.2 (-.07)	+ .0 (.00)
	= -7.8 (-.44)	=-10.2 (-.58)	= -3.1 (-.17)	=-10.2 (-.58)	= .0 (.00)	=-13.1 (-.74)	= .0 (.00)
PRE-PLANNED	.0 (.00)	.8 (.05)	7.3 (.41)	.8 (.05)	11.9 (.67)	.0 (.00)	11.9 (.67)
	+ 5.3 (.30)	+ 2.1 (.12)	+ 2.7 (.15)	+ 2.1 (.12)	+ 1.2 (.07)	+ .0 (.00)	+ 1.2 (.07)
	= 5.3 (.30)	= 2.9 (.16)	= 10.1 (.57)	= 2.9 (.16)	= 13.1 (.74)	= .0 (.00)	= 13.1 (.74)
VOR/C	-11.9 (-.67)	-11.0 (-.62)	-4.5 (-.25)	-11.0 (-.62)	.0 (.00)	-11.9 (-.67)	.0 (.00)
	+ 4.0 (.23)	+ .8 (.05)	+ 1.5 (.08)	+ .8 (.05)	+ .0 (.00)	+ -1.2 (-.07)	+ .0 (.00)
	= -7.8 (-.44)	=-10.2 (-.58)	= -3.1 (-.17)	=-10.2 (-.58)	= .0 (.00)	=-13.1 (-.74)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

PREFERRED ROUTE: GROUND, WIND AND TOTAL BENEFIT

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 9: MIA CLE

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	4.9 (.50)	5.6 (.57)	4.9 (.50)	9.8 (1.00)	.0 (.00)	9.8 (1.00)
	+ .0 (.00)	+ -4.9 (-.50)	+ -2.2 (-.23)	+ -4.9 (-.50)	+ -5.5 (-.56)	+ .0 (.00)	+ -5.5 (-.56)
	= .0 (.00)	= .0 (.00)	= 3.4 (.34)	= .0 (.00)	= 4.3 (.44)	= .0 (.00)	= 4.3 (.44)
SCI/NAFEC	-4.9 (-.50)	.0 (.00)	.7 (.07)	.0 (.00)	4.9 (.50)	-4.9 (-.50)	4.9 (.50)
	+ 4.9 (.50)	+ .0 (.00)	+ 2.7 (.27)	+ .0 (.00)	+ -.6 (-.06)	+ 4.9 (.50)	+ -.6 (-.06)
	= -.0 (-.00)	= .0 (.00)	= 3.3 (.34)	= .0 (.00)	= 4.3 (.44)	= -.0 (-.00)	= 4.3 (.44)
FAA/NAFEC	-5.6 (-.57)	-.7 (-.07)	.0 (.00)	-.7 (-.07)	4.2 (.43)	-5.6 (-.57)	4.2 (.43)
	+ 2.2 (.23)	+ -2.7 (-.27)	+ .0 (.00)	+ -2.7 (-.27)	+ -3.3 (-.33)	+ 2.2 (.23)	+ -3.3 (-.33)
	= -3.4 (-.34)	= -3.3 (-.34)	= .0 (.00)	= -3.3 (-.34)	= 1.0 (.10)	= -3.4 (-.34)	= 1.0 (.10)
SCI/FA/NAFEC	-4.9 (-.50)	.0 (.00)	.7 (.07)	.0 (.00)	4.9 (.50)	-4.9 (-.50)	4.9 (.50)
	+ 4.9 (.50)	+ .0 (.00)	+ 2.7 (.27)	+ .0 (.00)	+ -.6 (-.06)	+ 4.9 (.50)	+ -.6 (-.06)
	= -.0 (-.00)	= .0 (.00)	= 3.3 (.34)	= .0 (.00)	= 4.3 (.44)	= -.0 (-.00)	= 4.3 (.44)
VOR/A	-9.8 (-1.00)	-4.9 (-.50)	-4.2 (-.43)	-4.9 (-.50)	.0 (.00)	-9.8 (-1.00)	.0 (.00)
	+ 5.5 (.56)	+ .6 (.06)	+ 3.3 (.33)	+ .6 (.06)	+ .0 (.00)	+ 5.5 (.56)	+ .0 (.00)
	= -4.3 (-.44)	= -4.3 (-.44)	= -1.0 (-.10)	= -4.3 (-.44)	= .0 (.00)	= -4.3 (-.44)	= .0 (.00)
PRE-PLANNED	.0 (.00)	4.9 (.50)	5.6 (.57)	4.9 (.50)	9.8 (1.00)	.0 (.00)	9.8 (1.00)
	+ .0 (.00)	+ -4.9 (-.50)	+ -2.2 (-.23)	+ -4.9 (-.50)	+ -5.5 (-.56)	+ .0 (.00)	+ -5.5 (-.56)
	= .0 (.00)	= .0 (.00)	= 3.4 (.34)	= .0 (.00)	= 4.3 (.44)	= .0 (.00)	= 4.3 (.44)
VOR/C	-9.8 (-1.00)	-4.9 (-.50)	-4.2 (-.43)	-4.9 (-.50)	.0 (.00)	-9.8 (-1.00)	.0 (.00)
	+ 5.5 (.56)	+ .6 (.06)	+ 3.3 (.33)	+ .6 (.06)	+ .0 (.00)	+ 5.5 (.56)	+ .0 (.00)
	= -4.3 (-.44)	= -4.3 (-.44)	= -1.0 (-.10)	= -4.3 (-.44)	= .0 (.00)	= -4.3 (-.44)	= .0 (.00)

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ROUTE STRUCTURE COMPARISONS

ALTERNATE ROUTE BENEFIT: PREFERRED ROUTE, ADDITIONAL ROUTES AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 91 MIA CLE

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	.0 (.00)	3.4 (.34)	.0 (.00)	4.3 (.44)	.0 (.00)	4.3 (.44)
	+ .0 (.00)	+ -.1 (-.01)	+ .0 (.00)	+ -.1 (-.01)	+ .0 (.00)	+ -1.7 (-.17)	+ .0 (.00)
	= .0 (.00)	= -.1 (-.01)	= 3.4 (.34)	= -.1 (-.01)	= 4.3 (.44)	= -1.7 (-.17)	= 4.3 (.44)
SCI/NAFEC	-.0 (-.00)	.0 (.00)	3.3 (.34)	.0 (.00)	4.3 (.44)	-.0 (-.00)	4.3 (.44)
	+ .1 (.01)	+ .0 (.00)	+ .1 (.01)	+ .0 (.00)	+ .1 (.01)	+ -1.6 (-.16)	+ .1 (.01)
	= .1 (.01)	= .0 (.00)	= 3.4 (.35)	= .0 (.00)	= 4.4 (.45)	= -1.6 (-.16)	= 4.4 (.45)
FAA/NAFEC	-3.4 (-.34)	-3.3 (-.34)	.0 (.00)	-3.3 (-.34)	1.0 (.10)	-3.4 (-.34)	1.0 (.10)
	+ .0 (.00)	+ -.1 (-.01)	+ .0 (.00)	+ -.1 (-.01)	+ .0 (.00)	+ -1.7 (-.17)	+ .0 (.00)
	= -3.4 (-.34)	= -3.4 (-.35)	= .0 (.00)	= -3.4 (-.35)	= 1.0 (.10)	= -5.1 (-.52)	= 1.0 (.10)
SCI/FA/NAFEC	-.0 (-.00)	.0 (.00)	3.3 (.34)	.0 (.00)	4.3 (.44)	-.0 (-.00)	4.3 (.44)
	+ .1 (.01)	+ .0 (.00)	+ .1 (.01)	+ .0 (.00)	+ .1 (.01)	+ -1.6 (-.16)	+ .1 (.01)
	= .1 (.01)	= .0 (.00)	= 3.4 (.35)	= .0 (.00)	= 4.4 (.45)	= -1.6 (-.16)	= 4.4 (.45)
VOR/A	-4.3 (-.44)	-4.3 (-.44)	-1.0 (-.10)	-4.3 (-.44)	.0 (.00)	-4.3 (-.44)	.0 (.00)
	+ .0 (.00)	+ -.1 (-.01)	+ .0 (.00)	+ -.1 (-.01)	+ .0 (.00)	+ -1.7 (-.17)	+ .0 (.00)
	= -4.3 (-.44)	= -4.4 (-.45)	= -1.0 (-.10)	= -4.4 (-.45)	= .0 (.00)	= -6.0 (-.61)	= .0 (.00)
PRE-PLANNED	.0 (.00)	.0 (.00)	3.4 (.34)	.0 (.00)	4.3 (.44)	.0 (.00)	4.3 (.44)
	+ 1.7 (.17)	+ 1.6 (.16)	+ 1.7 (.17)	+ 1.6 (.16)	+ 1.7 (.17)	+ .0 (.00)	+ 1.7 (.17)
	= 1.7 (.17)	= 1.6 (.16)	= 5.1 (.51)	= 1.6 (.16)	= 6.0 (.61)	= .0 (.00)	= 6.0 (.61)
VOR/C	-4.3 (-.44)	-4.3 (-.44)	-1.0 (-.10)	-4.3 (-.44)	.0 (.00)	-4.3 (-.44)	.0 (.00)
	+ .0 (.00)	+ -.1 (-.01)	+ .0 (.00)	+ -.1 (-.01)	+ .0 (.00)	+ -1.7 (-.17)	+ .0 (.00)
	= -4.3 (-.44)	= -4.4 (-.45)	= -1.0 (-.10)	= -4.4 (-.45)	= .0 (.00)	= -6.0 (-.61)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ROUTE STRUCTURE BENEFIT: GROUND, WIND AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 91 MIA CLE

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	4.9 (.50)	5.6 (.57)	4.9 (.50)	9.8 (1.00)	.0 (.00)	9.8 (1.00)
	+ .0 (.00)	+ -5.0 (-.51)	+ -2.2 (-.23)	+ -5.0 (-.51)	+ -5.5 (-.56)	+ -1.7 (-.17)	+ -5.5 (-.56)
	= .0 (.00)	= -.1 (-.01)	= 3.4 (.34)	= -.1 (-.01)	= 4.3 (.44)	= -1.7 (-.17)	= 4.3 (.44)
SCI/NAFEC	-4.9 (-.50)	.0 (.00)	.7 (.07)	.0 (.00)	4.9 (.50)	-4.9 (-.50)	4.9 (.50)
	+ 5.0 (.51)	+ .0 (.00)	+ 2.8 (.28)	+ .0 (.00)	+ -.5 (-.05)	+ 3.3 (.34)	+ -.5 (-.05)
	= .1 (.01)	= .0 (.00)	= 3.4 (.35)	= .0 (.00)	= 4.4 (.45)	= -1.6 (-.16)	= 4.4 (.45)
FAA/NAFEC	-5.6 (-.57)	-.7 (-.07)	.0 (.00)	-.7 (-.07)	4.2 (.43)	-5.6 (-.57)	4.2 (.43)
	+ 2.2 (.23)	+ -2.8 (-.28)	+ .0 (.00)	+ -2.8 (-.28)	+ -3.3 (-.33)	+ .6 (.06)	+ -3.3 (-.33)
	= -3.4 (-.34)	= -3.4 (-.35)	= .0 (.00)	= -3.4 (-.35)	= 1.0 (.10)	= -5.1 (-.52)	= 1.0 (.10)
SCI/FA/NAFEC	-4.9 (-.50)	.0 (.00)	.7 (.07)	.0 (.00)	4.9 (.50)	-4.9 (-.50)	4.9 (.50)
	+ 5.0 (.51)	+ .0 (.00)	+ 2.8 (.28)	+ .0 (.00)	+ -.5 (-.05)	+ 3.3 (.34)	+ -.5 (-.05)
	= .1 (.01)	= .0 (.00)	= 3.4 (.35)	= .0 (.00)	= 4.4 (.45)	= -1.6 (-.16)	= 4.4 (.45)
VOR/A	-9.8 (-1.00)	-4.9 (-.50)	-4.2 (-.43)	-4.9 (-.50)	.0 (.00)	-9.8 (-1.00)	.0 (.00)
	+ 5.5 (.56)	+ .5 (.05)	+ 3.3 (.33)	+ .5 (.05)	+ .0 (.00)	+ 3.8 (.39)	+ .0 (.00)
	= -4.3 (-.44)	= -4.4 (-.45)	= -1.0 (-.10)	= -4.4 (-.45)	= .0 (.00)	= -6.0 (-.61)	= .0 (.00)
PRE-PLANNED	.0 (.00)	4.9 (.50)	5.6 (.57)	4.9 (.50)	9.8 (1.00)	.0 (.00)	9.8 (1.00)
	+ 1.7 (.17)	+ -3.3 (-.34)	+ -.6 (-.06)	+ -3.3 (-.34)	+ -3.8 (-.39)	+ .0 (.00)	+ -3.8 (-.39)
	= 1.7 (.17)	= 1.6 (.16)	= 5.1 (.51)	= 1.6 (.16)	= 6.0 (.61)	= .0 (.00)	= 6.0 (.61)
VOR/C	-9.8 (-1.00)	-4.9 (-.50)	-4.2 (-.43)	-4.9 (-.50)	.0 (.00)	-9.8 (-1.00)	.0 (.00)
	+ 5.5 (.56)	+ .5 (.05)	+ 3.3 (.33)	+ .5 (.05)	+ .0 (.00)	+ 3.8 (.39)	+ .0 (.00)
	= -4.3 (-.44)	= -4.4 (-.45)	= -1.0 (-.10)	= -4.4 (-.45)	= .0 (.00)	= -6.0 (-.61)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

PREFERRED ROUTE: GROUND, WIND AND TOTAL BENEFIT

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 10: CLE MIA

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	4.0 (.44)	4.6 (.50)	4.0 (.44)	9.5 (1.01)	.0 (.00)	9.5 (1.01)
	+ .0 (.00)	+ -6.5 (-.70)	+ -6.4 (-.70)	+ -6.5 (-.70)	+ 9.7 (1.03)	+ .0 (.00)	+ 9.7 (1.03)
	= .0 (.00)	= -2.5 (-.27)	= -1.8 (-.20)	= -2.5 (-.27)	= 19.2 (2.04)	= .0 (.00)	= 19.2 (2.04)
SCI/NAFEC	-4.0 (-.43)	.0 (.00)	.6 (.06)	.0 (.00)	5.5 (.59)	-4.0 (-.43)	5.5 (.59)
	+ 6.5 (.70)	+ .0 (.00)	+ .0 (.01)	+ .0 (.00)	+ 16.2 (1.71)	+ 6.5 (.70)	+ 16.2 (1.71)
	= 2.5 (.27)	= .0 (.00)	= .6 (.07)	= .0 (.00)	= 21.7 (2.30)	= 2.5 (.27)	= 21.7 (2.30)
FAA/NAFEC	-4.6 (-.50)	-.6 (-.06)	.0 (.00)	-.6 (-.06)	5.0 (.53)	-4.6 (-.50)	5.0 (.53)
	+ 6.4 (.70)	+ -.0 (-.01)	+ .0 (.00)	+ -.0 (-.01)	+ 16.1 (1.71)	+ 6.4 (.70)	+ 16.1 (1.71)
	= 1.8 (.20)	= -.6 (-.07)	= .0 (.00)	= -.6 (-.07)	= 21.1 (2.24)	= 1.8 (.20)	= 21.1 (2.24)
SCI/FA/NAFEC	-4.0 (-.43)	.0 (.00)	.6 (.06)	.0 (.00)	5.5 (.59)	-4.0 (-.43)	5.5 (.59)
	+ 6.5 (.70)	+ .0 (.00)	+ .0 (.01)	+ .0 (.00)	+ 16.2 (1.71)	+ 6.5 (.70)	+ 16.2 (1.71)
	= 2.5 (.27)	= .0 (.00)	= .6 (.07)	= .0 (.00)	= 21.7 (2.30)	= 2.5 (.27)	= 21.7 (2.30)
VOR/A	-9.5 (-1.03)	-5.5 (-.60)	-5.0 (-.54)	-5.5 (-.60)	.0 (.00)	-9.5 (-1.03)	.0 (.00)
	+ -9.7 (-1.05)	+ -16.2 (-1.75)	+ -16.1 (-1.75)	+ -16.2 (-1.75)	+ .0 (.00)	+ -9.7 (-1.05)	+ .0 (.00)
	= -19.2 (-2.08)	= -21.7 (-2.35)	= -21.1 (-2.29)	= -21.7 (-2.35)	= .0 (.00)	= -19.2 (-2.08)	= .0 (.00)
PRE-PLANNED	.0 (.00)	4.0 (.44)	4.6 (.50)	4.0 (.44)	9.5 (1.01)	.0 (.00)	9.5 (1.01)
	+ .0 (.00)	+ -6.5 (-.70)	+ -6.4 (-.70)	+ -6.5 (-.70)	+ 9.7 (1.03)	+ .0 (.00)	+ 9.7 (1.03)
	= .0 (.00)	= -2.5 (-.27)	= -1.8 (-.20)	= -2.5 (-.27)	= 19.2 (2.04)	= .0 (.00)	= 19.2 (2.04)
VOR/C	-9.5 (-1.03)	-5.5 (-.60)	-5.0 (-.54)	-5.5 (-.60)	.0 (.00)	-9.5 (-1.03)	.0 (.00)
	+ -9.7 (-1.05)	+ -16.2 (-1.75)	+ -16.1 (-1.75)	+ -16.2 (-1.75)	+ .0 (.00)	+ -9.7 (-1.05)	+ .0 (.00)
	= -19.2 (-2.08)	= -21.7 (-2.35)	= -21.1 (-2.29)	= -21.7 (-2.35)	= .0 (.00)	= -19.2 (-2.08)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ALTERNATE ROUTE BENEFIT: PREFERRED ROUTE, ADDITIONAL ROUTES AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 101 CLE MIA

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	-2.5 (-.27)	-1.8 (-.20)	-2.5 (-.27)	19.2 (2.04)	.0 (.00)	19.2 (2.04)
	+ .0 (.00)	+ -1.6 (-.18)	+ -.3 (-.03)	+ -1.6 (-.18)	+ .0 (.00)	+ -4.8 (-.52)	+ .0 (.00)
	= .0 (.00)	= -4.1 (-.45)	= -2.1 (-.23)	= -4.1 (-.45)	= 19.2 (2.04)	= -4.8 (-.52)	= 19.2 (2.04)
SCI/NAFEC	2.5 (.27)	.0 (.00)	.6 (.07)	.0 (.00)	21.7 (2.30)	2.5 (.27)	21.7 (2.30)
	+ 1.6 (.18)	+ .0 (.00)	+ 1.4 (.15)	+ .0 (.00)	+ 1.6 (.17)	+ -3.2 (-.35)	+ 1.6 (.17)
	= 4.1 (.44)	= .0 (.00)	= 2.0 (.22)	= .0 (.00)	= 23.3 (2.47)	= -.7 (-.08)	= 23.3 (2.47)
FAA/NAFEC	1.8 (.20)	-.6 (-.07)	.0 (.00)	-.6 (-.07)	21.1 (2.24)	1.8 (.20)	21.1 (2.24)
	+ .3 (.03)	+ -1.4 (-.15)	+ .0 (.00)	+ -1.4 (-.15)	+ .3 (.03)	+ -4.6 (-.50)	+ .3 (.03)
	= 2.1 (.23)	= -2.0 (-.22)	= .0 (.00)	= -2.0 (-.22)	= 21.3 (2.26)	= -2.7 (-.30)	= 21.3 (2.26)
SCI/FA/NAFEC	2.5 (.27)	.0 (.00)	.6 (.07)	.0 (.00)	21.7 (2.30)	2.5 (.27)	21.7 (2.30)
	+ 1.6 (.18)	+ .0 (.00)	+ 1.4 (.15)	+ .0 (.00)	+ 1.6 (.17)	+ -3.2 (-.35)	+ 1.6 (.17)
	= 4.1 (.44)	= .0 (.00)	= 2.0 (.22)	= .0 (.00)	= 23.3 (2.47)	= -.7 (-.08)	= 23.3 (2.47)
VOR/A	-19.2 (-2.08)	-21.7 (-2.36)	-21.1 (-2.29)	-21.7 (-2.36)	.0 (.00)	-19.2 (-2.09)	.0 (.00)
	+ .0 (.00)	+ -1.6 (-.18)	+ -.3 (-.03)	+ -1.6 (-.18)	+ .0 (.00)	+ -4.8 (-.52)	+ .0 (.00)
	=-19.2 (-2.08)	=-23.3 (-2.54)	=-21.3 (-2.31)	=-23.3 (-2.54)	= .0 (.00)	=-24.1 (-2.62)	= .0 (.00)
PRE-PLANNED	.0 (.00)	-2.5 (-.27)	-1.8 (-.20)	-2.5 (-.27)	19.2 (2.04)	.0 (.00)	19.2 (2.04)
	+ 4.8 (.52)	+ 3.2 (.35)	+ 4.6 (.50)	+ 3.2 (.35)	+ 4.8 (.51)	+ .0 (.00)	+ 4.8 (.51)
	= 4.8 (.52)	= .7 (.08)	= 2.7 (.29)	= .7 (.08)	= 24.1 (2.55)	= .0 (.00)	= 24.1 (2.55)
VOR/C	-19.2 (-2.08)	-21.7 (-2.36)	-21.1 (-2.29)	-21.7 (-2.36)	.0 (.00)	-19.2 (-2.09)	.0 (.00)
	+ .0 (.00)	+ -1.6 (-.18)	+ -.3 (-.03)	+ -1.6 (-.18)	+ .0 (.00)	+ -4.8 (-.52)	+ .0 (.00)
	=-19.2 (-2.08)	=-23.3 (-2.54)	=-21.3 (-2.31)	=-23.3 (-2.54)	= .0 (.00)	=-24.1 (-2.62)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ROUTE STRUCTURE BENEFIT: GROUND, WIND AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 101 CLE MIA

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00) + .0 (.00) = .0 (.00)	4.0 (.44) + -8.1 (-.88) = -4.1 (-.45)	4.6 (.50) + -6.7 (-.72) = -2.1 (-.23)	4.0 (.44) + -8.1 (-.88) = -4.1 (-.45)	9.5 (1.01) + 9.7 (1.03) = 19.2 (2.04)	.0 (.00) + -4.8 (-.52) = -4.8 (-.52)	9.5 (1.01) + 9.7 (1.03) = 19.2 (2.04)
SCI/NAFEC	-4.0 (-.43) + 8.1 (.88) = 4.1 (.44)	.0 (.00) + .0 (.00) = .0 (.00)	.6 (.06) + 1.4 (.16) = 2.0 (.22)	.0 (.00) + .0 (.00) = .0 (.00)	5.5 (.59) + 17.8 (1.89) = 23.3 (2.47)	-4.0 (-.44) + 3.3 (.36) = -.7 (-.08)	5.5 (.59) + 17.8 (1.89) = 23.3 (2.47)
FAA/NAFEC	-4.6 (-.50) + 6.7 (.72) = 2.1 (.23)	-.6 (-.06) + -1.4 (-.16) = -2.0 (-.22)	.0 (.00) + .0 (.00) = .0 (.00)	-.6 (-.06) + -1.4 (-.16) = -2.0 (-.22)	5.0 (.53) + 16.4 (1.74) = 21.3 (2.26)	-4.6 (-.50) + 1.9 (.20) = -2.7 (-.30)	5.0 (.53) + 16.4 (1.74) = 21.3 (2.26)
SCI/FA/NAFEC	-4.0 (-.43) + 8.1 (.88) = 4.1 (.44)	.0 (.00) + .0 (.00) = .0 (.00)	.6 (.06) + 1.4 (.16) = 2.0 (.22)	.0 (.00) + .0 (.00) = .0 (.00)	5.5 (.59) + 17.8 (1.89) = 23.3 (2.47)	-4.0 (-.44) + 3.3 (.36) = -.7 (-.08)	5.5 (.59) + 17.8 (1.89) = 23.3 (2.47)
VOR/A	-9.5 (-1.03) + -9.7 (-1.05) =-19.2 (-2.08)	-5.5 (-.60) +-17.8 (-1.94) =-23.3 (-2.54)	-5.0 (-.54) +-16.4 (-1.78) =-21.3 (-2.31)	-5.5 (-.60) +-17.8 (-1.94) =-23.3 (-2.54)	.0 (.00) + .0 (.00) = .0 (.00)	-9.5 (-1.04) +-14.5 (-1.58) =-24.1 (-2.62)	.0 (.00) + .0 (.00) = .0 (.00)
PRE-PLANNED	.0 (.00) + 4.8 (.52) = 4.8 (.52)	4.0 (.44) + -3.3 (-.36) = .7 (.08)	4.6 (.50) + -1.9 (-.20) = 2.7 (.29)	4.0 (.44) + -3.3 (-.36) = .7 (.08)	9.5 (1.01) + 14.5 (1.54) = 24.1 (2.55)	.0 (.00) + .0 (.00) = .0 (.00)	9.5 (1.01) + 14.5 (1.54) = 24.1 (2.55)
VOR/C	-9.5 (-1.03) + -9.7 (-1.05) =-19.2 (-2.08)	-5.5 (-.60) +-17.8 (-1.94) =-23.3 (-2.54)	-5.0 (-.54) +-16.4 (-1.78) =-21.3 (-2.31)	-5.5 (-.60) +-17.8 (-1.94) =-23.3 (-2.54)	.0 (.00) + .0 (.00) = .0 (.00)	-9.5 (-1.04) +-14.5 (-1.58) =-24.1 (-2.62)	.0 (.00) + .0 (.00) = .0 (.00)

ROUTE STRUCTURE COMPARISONS

PREFERRED ROUTE: GROUND, WIND AND TOTAL BENEFIT

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 111 JFK SEA

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	1.2 (.05)	1.6 (.07)	1.2 (.05)	20.9 (.91)	.0 (.00)	20.9 (.91)
	+ .0 (.00)	+ 5.5 (.24)	+ -3.7 (-.16)	+ 5.5 (.24)	+ 9.9 (.43)	+ .0 (.00)	+ 9.9 (.43)
	= .0 (.00)	= 6.7 (.29)	= -2.1 (-.09)	= 6.7 (.29)	= 30.8 (1.34)	= .0 (.00)	= 30.8 (1.34)
SCI/NAFEC	-1.2 (-.05)	.0 (.00)	.4 (.02)	.0 (.00)	19.7 (.86)	-1.2 (-.05)	19.7 (.86)
	+ -5.5 (-.24)	+ .0 (.00)	+ -9.2 (-.40)	+ .0 (.00)	+ 4.4 (.19)	+ -5.5 (-.24)	+ 4.4 (.19)
	= -6.7 (-.30)	= .0 (.00)	= -8.7 (-.39)	= .0 (.00)	= 24.2 (1.05)	= -6.7 (-.30)	= 24.2 (1.05)
FAA/NAFEC	-1.6 (-.07)	-.4 (-.02)	.0 (.00)	-.4 (-.02)	19.3 (.84)	-1.6 (-.07)	19.3 (.84)
	+ 3.7 (.16)	+ 9.2 (.40)	+ .0 (.00)	+ 9.2 (.40)	+ 13.6 (.59)	+ 3.7 (.16)	+ 13.6 (.59)
	= 2.1 (.09)	= 8.7 (.38)	= .0 (.00)	= 8.7 (.38)	= 32.9 (1.43)	= 2.1 (.09)	= 32.9 (1.43)
SCI/FA/NAFEC	-1.2 (-.05)	.0 (.00)	.4 (.02)	.0 (.00)	19.7 (.86)	-1.2 (-.05)	19.7 (.86)
	+ -5.5 (-.24)	+ .0 (.00)	+ -9.2 (-.40)	+ .0 (.00)	+ 4.4 (.19)	+ -5.5 (-.24)	+ 4.4 (.19)
	= -6.7 (-.30)	= .0 (.00)	= -8.7 (-.39)	= .0 (.00)	= 24.2 (1.05)	= -6.7 (-.30)	= 24.2 (1.05)
VOR/A	-20.9 (-.92)	-19.7 (-.87)	-19.3 (-.85)	-19.7 (-.87)	.0 (.00)	-20.9 (-.92)	.0 (.00)
	+ -9.9 (-.44)	+ -4.4 (-.20)	+-13.6 (-.60)	+ -4.4 (-.20)	+ .0 (.00)	+ -9.9 (-.44)	+ .0 (.00)
	=-30.8 (-1.36)	=-24.2 (-1.06)	=-32.9 (-1.45)	=-24.2 (-1.06)	= .0 (.00)	=-30.8 (-1.36)	= .0 (.00)
PRE-PLANNED	.0 (.00)	1.2 (.05)	1.6 (.07)	1.2 (.05)	20.9 (.91)	.0 (.00)	20.9 (.91)
	+ .0 (.00)	+ 5.5 (.24)	+ -3.7 (-.16)	+ 5.5 (.24)	+ 9.9 (.43)	+ .0 (.00)	+ 9.9 (.43)
	= .0 (.00)	= 6.7 (.29)	= -2.1 (-.09)	= 6.7 (.29)	= 30.8 (1.34)	= .0 (.00)	= 30.8 (1.34)
VOR/C	-20.9 (-.92)	-19.7 (-.87)	-19.3 (-.85)	-19.7 (-.87)	.0 (.00)	-20.9 (-.92)	.0 (.00)
	+ -9.9 (-.44)	+ -4.4 (-.20)	+-13.6 (-.60)	+ -4.4 (-.20)	+ .0 (.00)	+ -9.9 (-.44)	+ .0 (.00)
	=-30.8 (-1.36)	=-24.2 (-1.06)	=-32.9 (-1.45)	=-24.2 (-1.06)	= .0 (.00)	=-30.8 (-1.36)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ALTERNATE ROUTE BENEFIT: PREFERRED ROUTE, ADDITIONAL ROUTES AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 111 JFK SEA

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	6.7 (.30)	-2.1 (-.09)	6.7 (.30)	30.8 (1.36)	.0 (.00)	30.8 (1.36)
	+ .0 (.00)	+ -3.8 (-.17)	+ 5.7 (.25)	+ -3.8 (-.17)	+-12.5 (-.55)	+ -3.3 (-.15)	+-12.5 (-.55)
	= .0 (.00)	= 2.8 (.13)	= 3.7 (.16)	= 2.8 (.13)	= 18.4 (.81)	= -3.3 (-.15)	= 18.4 (.81)
SCI/NAFEC	-6.7 (-.30)	.0 (.00)	-8.7 (-.39)	.0 (.00)	24.2 (1.06)	-6.7 (-.30)	24.2 (1.06)
	+ 3.8 (.17)	+ .0 (.00)	+ 9.6 (.42)	+ .0 (.00)	+ -8.6 (-.38)	+ .5 (.02)	+ -8.6 (-.38)
	= -2.8 (-.13)	= .0 (.00)	= .8 (.04)	= .0 (.00)	= 15.5 (.68)	= -6.2 (-.27)	= 15.5 (.68)
FAA/NAFEC	2.1 (.09)	8.7 (.39)	.0 (.00)	8.7 (.39)	32.9 (1.45)	2.1 (.09)	32.9 (1.45)
	+ -5.7 (-.25)	+ -9.6 (-.42)	+ .0 (.00)	+ -9.6 (-.42)	+-18.2 (-.80)	+ -9.1 (-.40)	+-18.2 (-.80)
	= -3.7 (-.16)	= -.8 (-.04)	= .0 (.00)	= -.8 (-.04)	= 14.7 (.65)	= -7.0 (-.31)	= 14.7 (.65)
SCI/FA/NAFEC	-6.7 (-.30)	.0 (.00)	-8.7 (-.39)	.0 (.00)	24.2 (1.06)	-6.7 (-.30)	24.2 (1.06)
	+ 3.8 (.17)	+ .0 (.00)	+ 9.6 (.42)	+ .0 (.00)	+ -8.6 (-.38)	+ .5 (.02)	+ -8.6 (-.38)
	= -2.8 (-.13)	= .0 (.00)	= .8 (.04)	= .0 (.00)	= 15.5 (.68)	= -6.2 (-.27)	= 15.5 (.68)
VOR/A	-30.8 (-1.37)	-24.2 (-1.07)	-32.9 (-1.46)	-24.2 (-1.07)	.0 (.00)	-30.8 (-1.37)	.0 (.00)
	+ 12.5 (.55)	+ 8.6 (.38)	+ 18.2 (.81)	+ 8.6 (.38)	+ .0 (.00)	+ 9.2 (.41)	+ .0 (.00)
	=-18.4 (-.82)	=-15.5 (-.69)	=-14.7 (-.65)	=-15.5 (-.69)	= .0 (.00)	=-21.7 (-.97)	= .0 (.00)
PRE-PLANNED	.0 (.00)	6.7 (.30)	-2.1 (-.09)	6.7 (.30)	30.8 (1.36)	.0 (.00)	30.8 (1.36)
	+ 3.3 (.15)	+ -.5 (-.02)	+ 9.1 (.40)	+ -.5 (-.02)	+ -9.2 (-.40)	+ .0 (.00)	+ -9.1 (-.40)
	= 3.3 (.15)	= 6.2 (.27)	= 7.0 (.31)	= 6.2 (.27)	= 21.7 (.96)	= .0 (.00)	= 21.7 (.96)
VOR/C	-30.8 (-1.37)	-24.2 (-1.07)	-32.9 (-1.46)	-24.2 (-1.07)	.0 (.00)	-30.8 (-1.37)	.0 (.00)
	+ 12.5 (.55)	+ 8.6 (.38)	+ 18.2 (.81)	+ 8.6 (.38)	+ -.0 (-.00)	+ 9.1 (.41)	+ .0 (.00)
	=-18.4 (-.82)	=-15.5 (-.69)	=-14.7 (-.65)	=-15.5 (-.69)	= -.0 (-.00)	=-21.7 (-.97)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ROUTE STRUCTURE BENEFIT: GROUND, WIND AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 111 JFK SEA

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	1.2 (.05)	1.6 (.07)	1.2 (.05)	20.9 (.92)	.0 (.00)	20.9 (.92)
	+ .0 (.00)	+ 1.7 (.07)	+ 2.1 (.09)	+ 1.7 (.07)	+ -2.6 (-.11)	+ -3.3 (-.15)	+ -2.5 (-.11)
	= .0 (.00)	= 2.8 (.13)	= 3.7 (.16)	= 2.8 (.13)	= 18.4 (.81)	= -3.3 (-.15)	= 18.4 (.81)
SCI/NAFEC	-1.2 (-.05)	.0 (.00)	.4 (.02)	.0 (.00)	19.7 (.87)	-1.2 (-.05)	19.7 (.87)
	+ -1.7 (-.07)	+ .0 (.00)	+ .4 (.02)	+ .0 (.00)	+ -4.2 (-.19)	+ -5.0 (-.22)	+ -4.2 (-.18)
	= -2.8 (-.13)	= .0 (.00)	= .8 (.04)	= .0 (.00)	= 15.5 (.68)	= -6.2 (-.27)	= 15.5 (.68)
FAA/NAFEC	-1.6 (-.07)	-.4 (-.02)	.0 (.00)	-.4 (-.02)	19.3 (.85)	-1.6 (-.07)	19.3 (.85)
	+ -2.1 (-.09)	+ -.4 (-.02)	+ .0 (.00)	+ -.4 (-.02)	+ -4.6 (-.20)	+ -5.4 (-.24)	+ -4.6 (-.20)
	= -3.7 (-.16)	= -.8 (-.04)	= .0 (.00)	= -.8 (-.04)	= 14.7 (.65)	= -7.0 (-.31)	= 14.7 (.65)
SCI/FA/NAFEC	-1.2 (-.05)	.0 (.00)	.4 (.02)	.0 (.00)	19.7 (.87)	-1.2 (-.05)	19.7 (.87)
	+ -1.7 (-.07)	+ .0 (.00)	+ .4 (.02)	+ .0 (.00)	+ -4.2 (-.19)	+ -5.0 (-.22)	+ -4.2 (-.18)
	= -2.8 (-.13)	= .0 (.00)	= .8 (.04)	= .0 (.00)	= 15.5 (.68)	= -6.2 (-.27)	= 15.5 (.68)
VOR/A	-20.9 (-.93)	-19.7 (-.87)	-19.3 (-.86)	-19.7 (-.87)	.0 (.00)	-20.9 (-.93)	.0 (.00)
	+ 2.6 (.11)	+ 4.2 (.19)	+ 4.6 (.20)	+ 4.2 (.19)	+ .0 (.00)	+ -.8 (-.03)	+ .0 (.00)
	=-18.4 (-.82)	=-15.5 (-.69)	=-14.7 (-.65)	=-15.5 (-.69)	= .0 (.00)	=-21.7 (-.97)	= .0 (.00)
PRE-PLANNED	.0 (.00)	1.2 (.05)	1.6 (.07)	1.2 (.05)	20.9 (.92)	.0 (.00)	20.9 (.92)
	+ 3.3 (.15)	+ 5.0 (.22)	+ 5.4 (.24)	+ 5.0 (.22)	+ .8 (.03)	+ .0 (.00)	+ .8 (.04)
	= 3.3 (.15)	= 6.2 (.27)	= 7.0 (.31)	= 6.2 (.27)	= 21.7 (.96)	= .0 (.00)	= 21.7 (.96)
VOR/C	-20.9 (-.93)	-19.7 (-.87)	-19.3 (-.86)	-19.7 (-.87)	.0 (.00)	-20.9 (-.93)	.0 (.00)
	+ 2.5 (.11)	+ 4.2 (.19)	+ 4.6 (.20)	+ 4.2 (.19)	+ -.0 (-.00)	+ -.8 (-.04)	+ .0 (.00)
	=-18.4 (-.82)	=-15.5 (-.69)	=-14.7 (-.65)	=-15.5 (-.69)	= -.0 (-.00)	=-21.7 (-.97)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

PREFERRED ROUTE: GROUND, WIND AND TOTAL BENEFIT

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 121 SEA JFK

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	3.0 (.15)	1.4 (.07)	1.4 (.07)	30.4 (1.51)	.0 (.00)	30.4 (1.51)
	+ .0 (.00)	+ -2.7 (-.13)	+ -.5 (-.03)	+ -.5 (-.03)	+ -5.9 (-.30)	+ .0 (.00)	+ -5.9 (-.30)
	= .0 (.00)	= .3 (.02)	= .8 (.04)	= .8 (.04)	= 24.5 (1.22)	= .0 (.00)	= 24.5 (1.22)
SCI/NAFEC	-3.0 (-.15)	.0 (.00)	-1.6 (-.08)	-1.6 (-.08)	27.4 (1.36)	-3.0 (-.15)	27.4 (1.36)
	+ 2.7 (.13)	+ .0 (.00)	+ 2.2 (.11)	+ 2.2 (.11)	+ -3.3 (-.16)	+ 2.7 (.13)	+ -3.3 (-.16)
	= -.3 (-.02)	= .0 (.00)	= .5 (.03)	= .5 (.03)	= 24.1 (1.20)	= -.3 (-.02)	= 24.1 (1.20)
FAA/NAFEC	-1.4 (-.07)	1.6 (.08)	.0 (.00)	.0 (.00)	29.0 (1.44)	-1.4 (-.07)	29.0 (1.44)
	+ .5 (.03)	+ -2.2 (-.11)	+ .0 (.00)	+ .0 (.00)	+ -5.4 (-.27)	+ .5 (.03)	+ -5.4 (-.27)
	= -.8 (-.04)	= -.5 (-.03)	= .0 (.00)	= .0 (.00)	= 23.6 (1.18)	= -.8 (-.04)	= 23.6 (1.18)
SCI/FAA/NAFEC	-1.4 (-.07)	1.6 (.08)	.0 (.00)	.0 (.00)	29.0 (1.44)	-1.4 (-.07)	29.0 (1.44)
	+ .5 (.03)	+ -2.2 (-.11)	+ .0 (.00)	+ .0 (.00)	+ -5.4 (-.27)	+ .5 (.03)	+ -5.4 (-.27)
	= -.8 (-.04)	= -.5 (-.03)	= .0 (.00)	= .0 (.00)	= 23.6 (1.18)	= -.8 (-.04)	= 23.6 (1.18)
VOR/A	-30.4 (-1.53)	-27.4 (-1.38)	-29.0 (-1.46)	-29.0 (-1.46)	.0 (.00)	-30.4 (-1.53)	.0 (.00)
	+ 5.9 (.30)	+ 3.3 (.16)	+ 5.4 (.27)	+ 5.4 (.27)	+ .0 (.00)	+ 5.9 (.30)	+ .0 (.00)
	=-24.5 (-1.23)	=-24.1 (-1.22)	=-23.6 (-1.19)	=-23.6 (-1.19)	= .0 (.00)	=-24.5 (-1.23)	= .0 (.00)
PRE-PLANNED	.0 (.00)	3.0 (.15)	1.4 (.07)	1.4 (.07)	30.4 (1.51)	.0 (.00)	30.4 (1.51)
	+ .0 (.00)	+ -2.7 (-.13)	+ -.5 (-.03)	+ -.5 (-.03)	+ -5.9 (-.30)	+ .0 (.00)	+ -5.9 (-.30)
	= .0 (.00)	= .3 (.02)	= .8 (.04)	= .8 (.04)	= 24.5 (1.22)	= .0 (.00)	= 24.5 (1.22)
VOR/C	-30.4 (-1.53)	-27.4 (-1.38)	-29.0 (-1.46)	-29.0 (-1.46)	.0 (.00)	-30.4 (-1.53)	.0 (.00)
	+ 5.9 (.30)	+ 3.3 (.16)	+ 5.4 (.27)	+ 5.4 (.27)	+ .0 (.00)	+ 5.9 (.30)	+ .0 (.00)
	=-24.5 (-1.23)	=-24.1 (-1.22)	=-23.6 (-1.19)	=-23.6 (-1.19)	= .0 (.00)	=-24.5 (-1.23)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

ALTERNATE ROUTE BENEFIT: PREFERRED ROUTE, ADDITIONAL ROUTES AND TOTAL

DATA BASED ON RUNS 1 THROUGH 39

AIRPORT PAIR 121 SEA JFK

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	.3 (.02)	.8 (.04)	.8 (.04)	24.5 (1.23)	.0 (.00)	24.5 (1.22)
	+ .0 (.00)	+ 2.6 (.13)	+ .1 (.00)	+ .1 (.00)	+ -6.2 (-.31)	+ -2.5 (-.13)	+ 3.8 (.19)
	= .0 (.00)	= 2.9 (.15)	= .9 (.05)	= .9 (.05)	= 18.3 (.92)	= -2.5 (-.13)	= 28.3 (1.41)
SCI/NAFEC	-.3 (-.02)	.0 (.00)	.5 (.03)	.5 (.03)	24.1 (1.21)	-.3 (-.02)	24.1 (1.20)
	+ -2.6 (-.13)	+ .0 (.00)	+ -2.5 (-.13)	+ -2.5 (-.13)	+ -8.8 (-.44)	+ -5.1 (-.26)	+ 1.2 (.06)
	= -2.9 (-.15)	= .0 (.00)	= -2.0 (-.10)	= -2.0 (-.10)	= 15.4 (.77)	= -5.4 (-.27)	= 25.4 (1.26)
FAA/NAFEC	-.8 (-.04)	-.5 (-.03)	.0 (.00)	.0 (.00)	23.6 (1.18)	-.8 (-.04)	23.6 (1.18)
	+ -.1 (-.00)	+ 2.5 (.13)	+ .0 (.00)	+ .0 (.00)	+ -6.3 (-.31)	+ -2.6 (-.13)	+ 3.7 (.19)
	= -.9 (-.05)	= 2.0 (.10)	= .0 (.00)	= .0 (.00)	= 17.3 (.87)	= -3.4 (-.17)	= 27.3 (1.36)
SCI/FA/NAFEC	-.8 (-.04)	-.5 (-.03)	.0 (.00)	.0 (.00)	23.6 (1.18)	-.8 (-.04)	23.6 (1.18)
	+ -.1 (-.00)	+ 2.5 (.13)	+ .0 (.00)	+ .0 (.00)	+ -6.3 (-.31)	+ -2.6 (-.13)	+ 3.7 (.19)
	= -.9 (-.05)	= 2.0 (.10)	= .0 (.00)	= .0 (.00)	= 17.3 (.87)	= -3.4 (-.17)	= 27.3 (1.36)
VOR/A	-24.5 (-1.24)	-24.1 (-1.22)	-23.6 (-1.19)	-23.6 (-1.19)	.0 (.00)	-24.5 (-1.24)	.0 (.00)
	+ 6.2 (.31)	+ 8.8 (.44)	+ 6.3 (.32)	+ 6.3 (.32)	+ .0 (.00)	+ 3.7 (.19)	+ 10.0 (.50)
	=-18.3 (-.92)	=-15.4 (-.78)	=-17.3 (-.88)	=-17.3 (-.88)	= .0 (.00)	=-20.7 (-1.05)	= 10.0 (.50)
PRE-PLANNED	.0 (.00)	.3 (.02)	.8 (.04)	.8 (.04)	24.5 (1.23)	.0 (.00)	24.5 (1.22)
	+ 2.5 (.13)	+ 5.1 (.26)	+ 2.6 (.13)	+ 2.6 (.13)	+ -3.7 (-.19)	+ .0 (.00)	+ 6.3 (.31)
	= 2.5 (.13)	= 5.4 (.27)	= 3.4 (.17)	= 3.4 (.17)	= 20.7 (1.04)	= .0 (.00)	= 30.7 (1.53)
VOR/C	-24.5 (-1.24)	-24.1 (-1.22)	-23.6 (-1.19)	-23.6 (-1.19)	.0 (.00)	-24.5 (-1.24)	.0 (.00)
	+ -3.8 (-.19)	+ -1.2 (-.06)	+ -3.7 (-.19)	+ -3.7 (-.19)	+-10.0 (-.50)	+ -6.3 (-.32)	+ .0 (.00)
	=-28.3 (-1.43)	=-25.4 (-1.28)	=-27.3 (-1.38)	=-27.3 (-1.38)	=-10.0 (-.50)	=-30.7 (-1.56)	= .0 (.00)

ROUTE STRUCTURE COMPARISONS

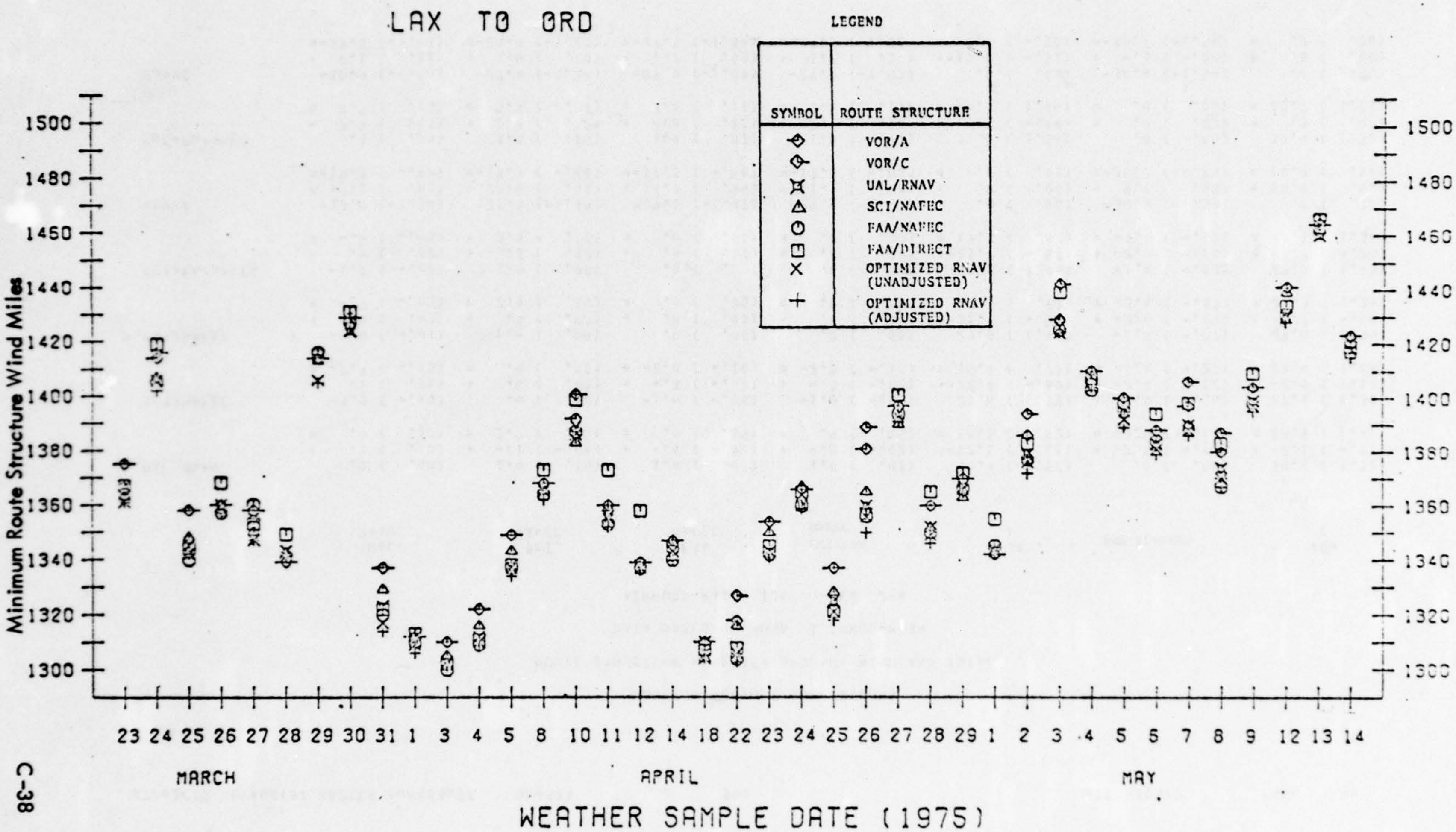
ROUTE STRUCTURE BENEFIT: GROUND, WIND AND TOTAL

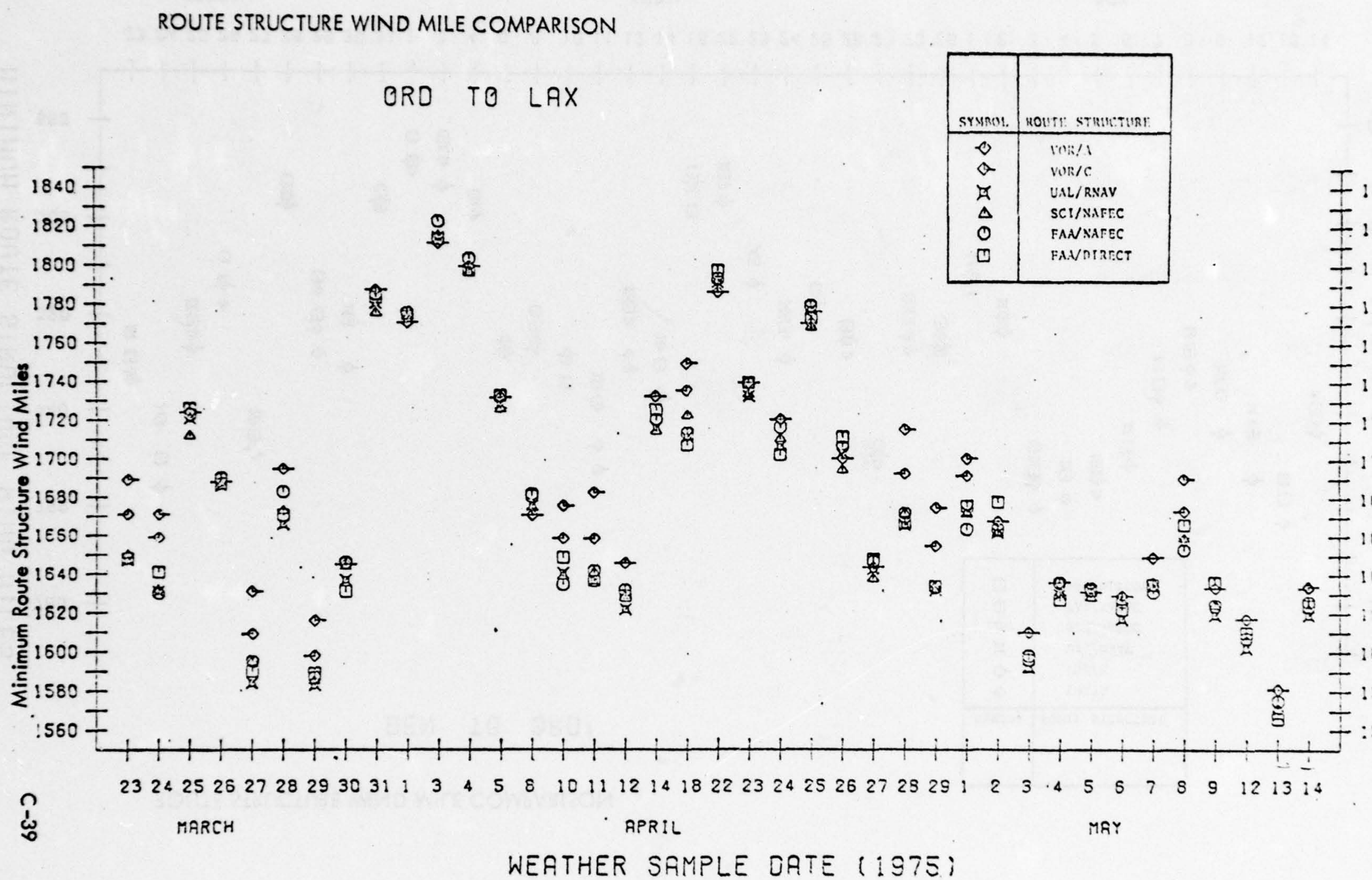
DATA BASED ON RUNS 1 THROUGH 39

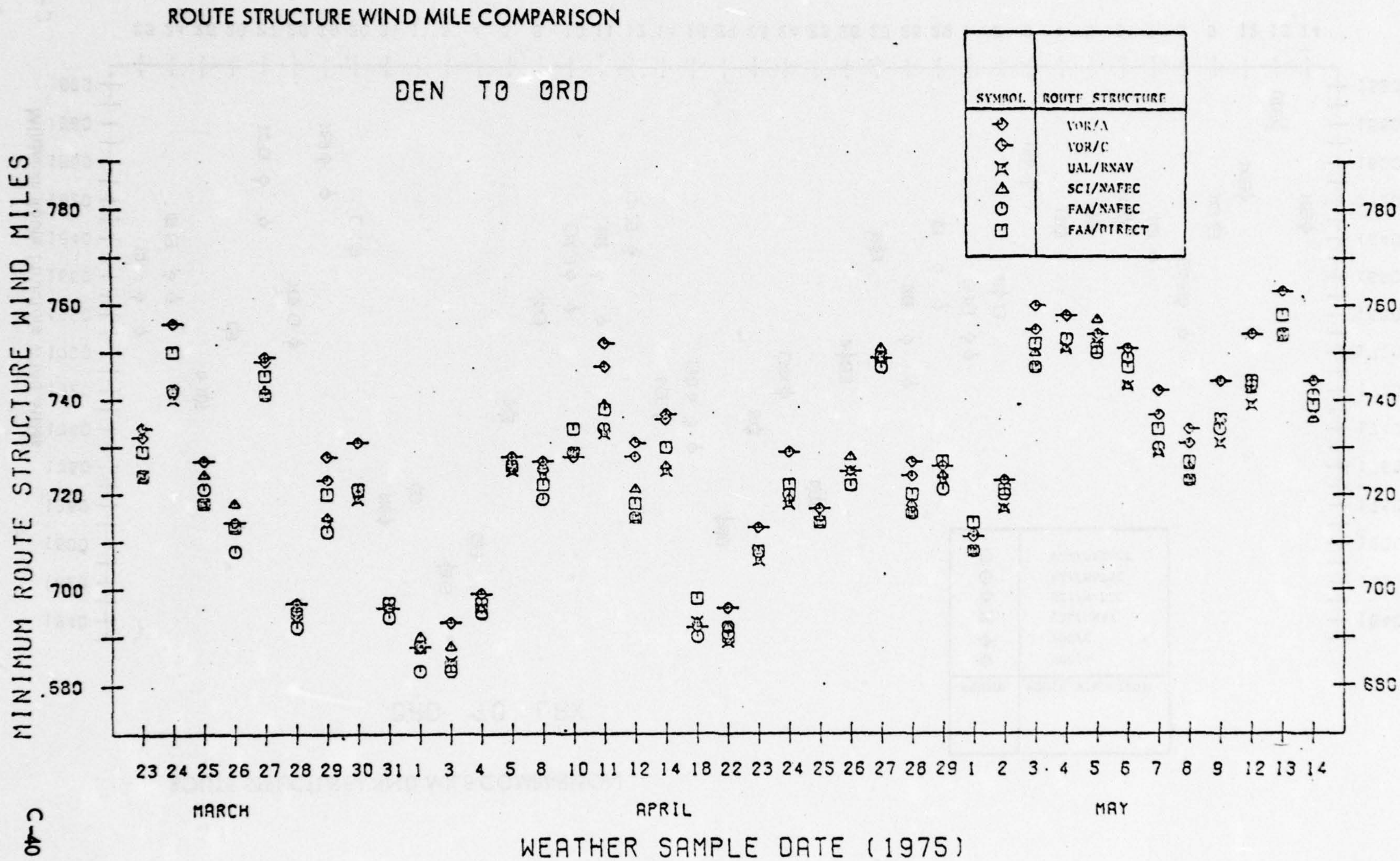
AIRPORT PAIR 12: SEA JFK

	UAL RNAV	SCI NAFEC	FAA NAFEC	SCI/FAA NAFEC	VOR A	PRE-PLANNED	VOR C
UAL RNAV	.0 (.00)	3.0 (.15)	1.4 (.07)	1.4 (.07)	30.4 (1.52)	.0 (.00)	30.4 (1.52)
	+ .0 (.00)	+ -.1 (-.01)	+ -.4 (-.02)	+ -.4 (-.02)	+-12.1 (-.61)	+ -2.5 (-.13)	+ -2.1 (-.11)
	= .0 (.00)	= 2.9 (.15)	= .9 (.05)	= .9 (.05)	= 18.3 (.92)	= -2.5 (-.13)	= 28.3 (1.41)
SCI/NAFEC	-3.0 (-.15)	.0 (.00)	-1.6 (-.08)	-1.6 (-.08)	27.4 (1.37)	-3.0 (-.15)	27.4 (1.37)
	+ .1 (.01)	+ .0 (.00)	+ -.3 (-.02)	+ -.3 (-.02)	+-12.0 (-.60)	+ -2.4 (-.12)	+ -2.0 (-.10)
	= -2.9 (-.15)	= .0 (.00)	= -2.0 (-.10)	= -2.0 (-.10)	= 15.4 (.77)	= -5.4 (-.27)	= 25.4 (1.26)
FAA/NAFEC	-1.4 (-.07)	1.6 (.08)	.0 (.00)	.0 (.00)	29.0 (1.46)	-1.4 (-.07)	29.0 (1.45)
	+ .4 (.02)	+ .3 (.02)	+ .0 (.00)	+ .0 (.00)	+-11.7 (-.59)	+ -2.0 (-.10)	+ -1.7 (-.08)
	= -.9 (-.05)	= 2.0 (.10)	= .0 (.00)	= .0 (.00)	= 17.3 (.87)	= -3.4 (-.17)	= 27.3 (1.36)
SCI/FA/NAFEC	-1.4 (-.07)	1.6 (.08)	.0 (.00)	.0 (.00)	29.0 (1.46)	-1.4 (-.07)	29.0 (1.45)
	+ .4 (.02)	+ .3 (.02)	+ .0 (.00)	+ .0 (.00)	+-11.7 (-.59)	+ -2.0 (-.10)	+ -1.7 (-.08)
	= -.9 (-.05)	= 2.0 (.10)	= .0 (.00)	= .0 (.00)	= 17.3 (.87)	= -3.4 (-.17)	= 27.3 (1.36)
VOR/A	-30.4 (-1.50)	-27.4 (-1.38)	-29.0 (-1.47)	-29.0 (-1.47)	.0 (.00)	-30.4 (-1.54)	.0 (.00)
	+ 12.1 (.61)	+ 12.0 (.61)	+ 11.7 (.59)	+ 11.7 (.59)	+ .0 (.00)	+ 9.7 (.49)	+ 10.0 (.50)
	=-18.3 (-.92)	=-15.4 (-.78)	=-17.3 (-.88)	=-17.3 (-.88)	= .0 (.00)	=-20.7 (-1.05)	= 10.0 (.50)
PRE-PLANNED	.0 (.00)	3.0 (.15)	1.4 (.07)	1.4 (.07)	30.4 (1.52)	.0 (.00)	30.4 (1.52)
	+ 2.5 (.13)	+ 2.4 (.12)	+ 2.0 (.10)	+ 2.0 (.10)	+ -9.7 (-.48)	+ .0 (.00)	+ .3 (.02)
	= 2.5 (.13)	= 5.4 (.27)	= 3.4 (.17)	= 3.4 (.17)	= 20.7 (1.04)	= .0 (.00)	= 30.7 (1.53)
VOR/C	-30.4 (-1.54)	-27.4 (-1.38)	-29.0 (-1.47)	-29.0 (-1.47)	.0 (.00)	-30.4 (-1.54)	.0 (.00)
	+ 2.1 (.11)	+ 2.0 (.10)	+ 1.7 (.09)	+ 1.7 (.09)	+-10.0 (-.50)	+ -.3 (-.02)	+ .0 (.00)
	=-28.3 (-1.43)	=-25.4 (-1.28)	=-27.3 (-1.38)	=-27.3 (-1.38)	=-10.0 (-.50)	=-30.7 (-1.56)	= .0 (.00)

ROUTE STRUCTURE WIND MILE COMPARISON



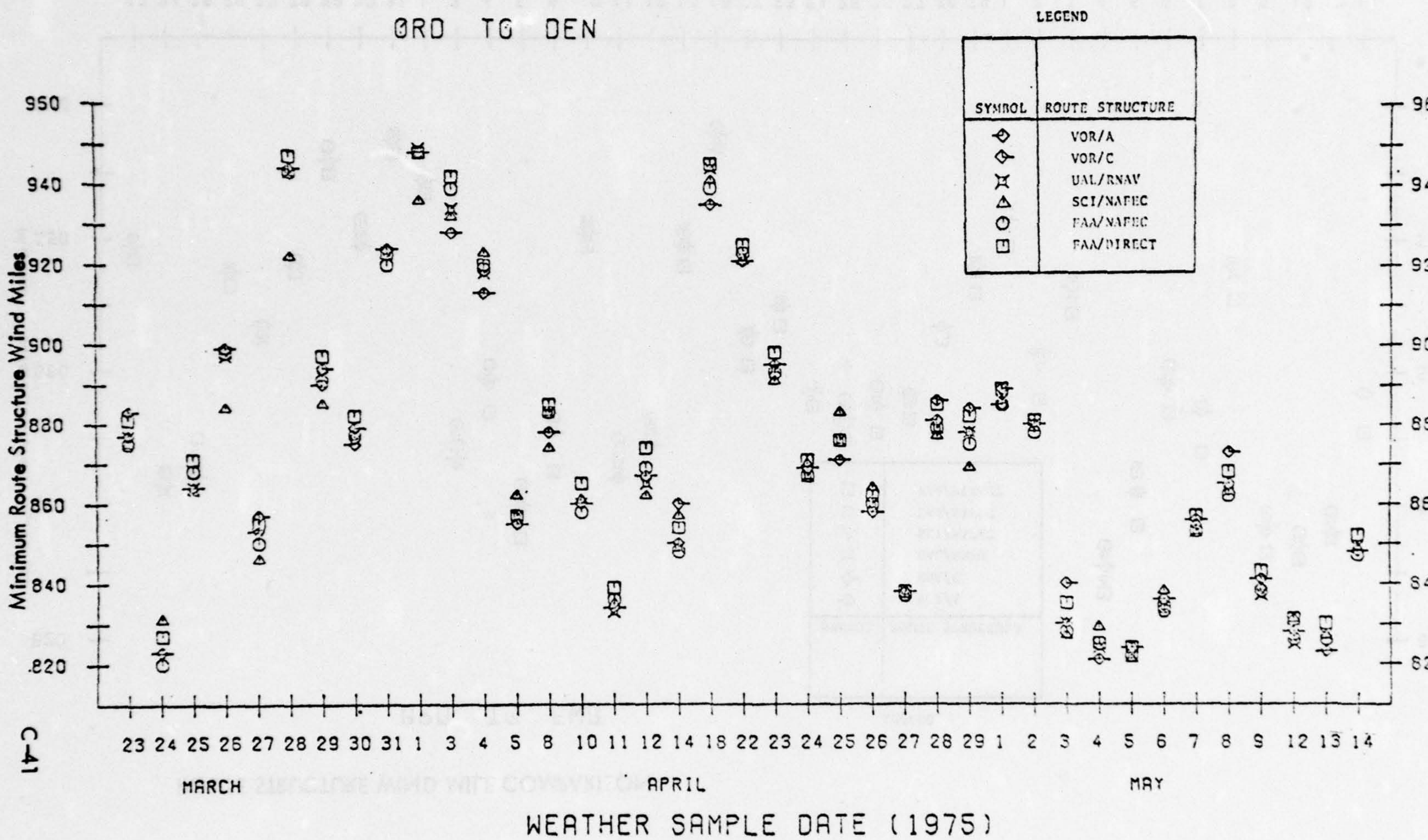

ROUTE STRUCTURE WIND MILE COMPARISON
ORD TO LAX
SYMBOL
ROUTE STRUCTURE
VOR/A
VOR/C
UAL/RNAV
SCI/NAFEC
FAA/NAFEC
FAA/DIRECT
Minimum Route Structure Wind Miles
1840
1820
1800
1780
1760
1740
1720
1700
1680
1660
1640
1620
1600
1580
1560
23 24 25 26 27 28 29 30 31 1 3 4 5 8 10 11 12 14 18 22 23 24 25 26 27 28 29 1 2 3 4 5 6 7 8 9 12 13 14
MARCH
APRIL
MAY
WEATHER SAMPLE DATE (1975)



ROUTE STRUCTURE WIND MILE COMPARISON
DEN TO ORD
SYMBOL
ROUTE STRUCTURE
VOR/A
VOR/C
UAL/RNAV
SCI/NAFEC
FAA/NAFEC
FAA/DIRECT
MINIMUM ROUTE STRUCTURE WIND MILES
780
760
740
720
700
680
23 24 25 26 27 28 29 30 31 1 3 4 5 8 10 11 12 14 18 22 23 24 25 26 27 28 29 1 2 3 4 5 6 7 8 9 12 13 14
MARCH
APRIL
MAY
WEATHER SAMPLE DATE (1975)

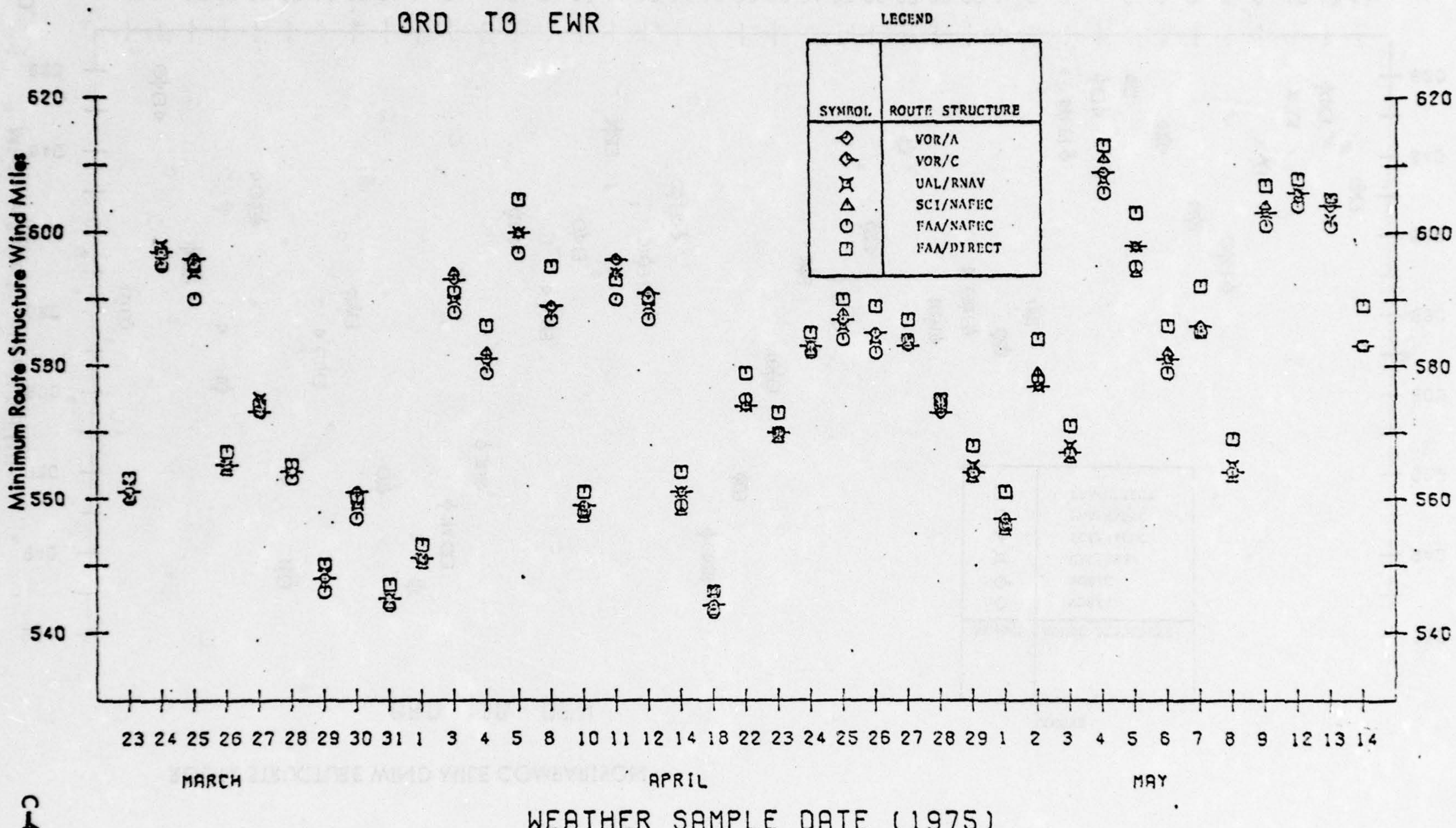
ROUTE STRUCTURE WIND MILE COMPARISON

ØRD TO DEN



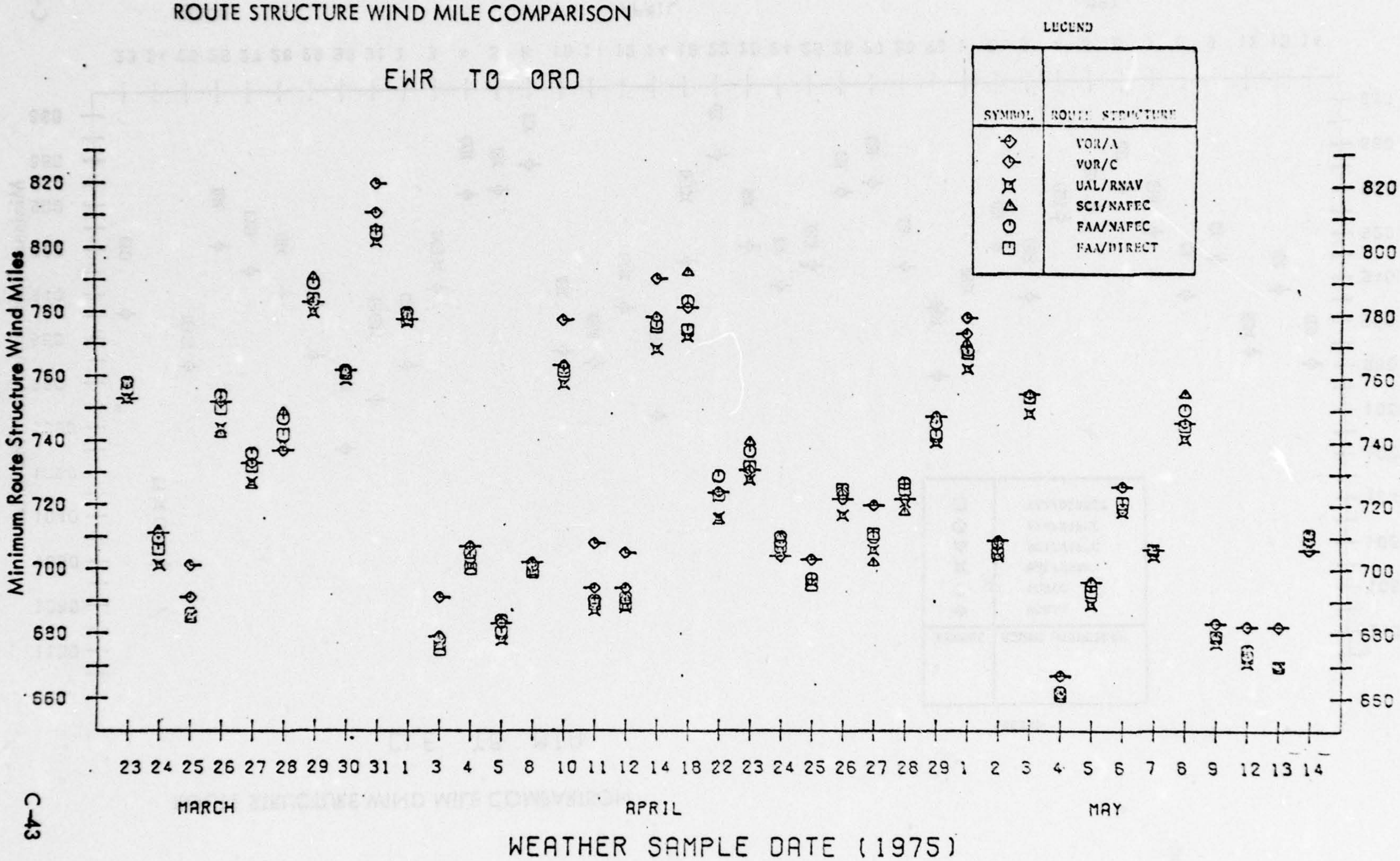
ROUTE STRUCTURE WIND MILE COMPARISON

ORD TO EWR



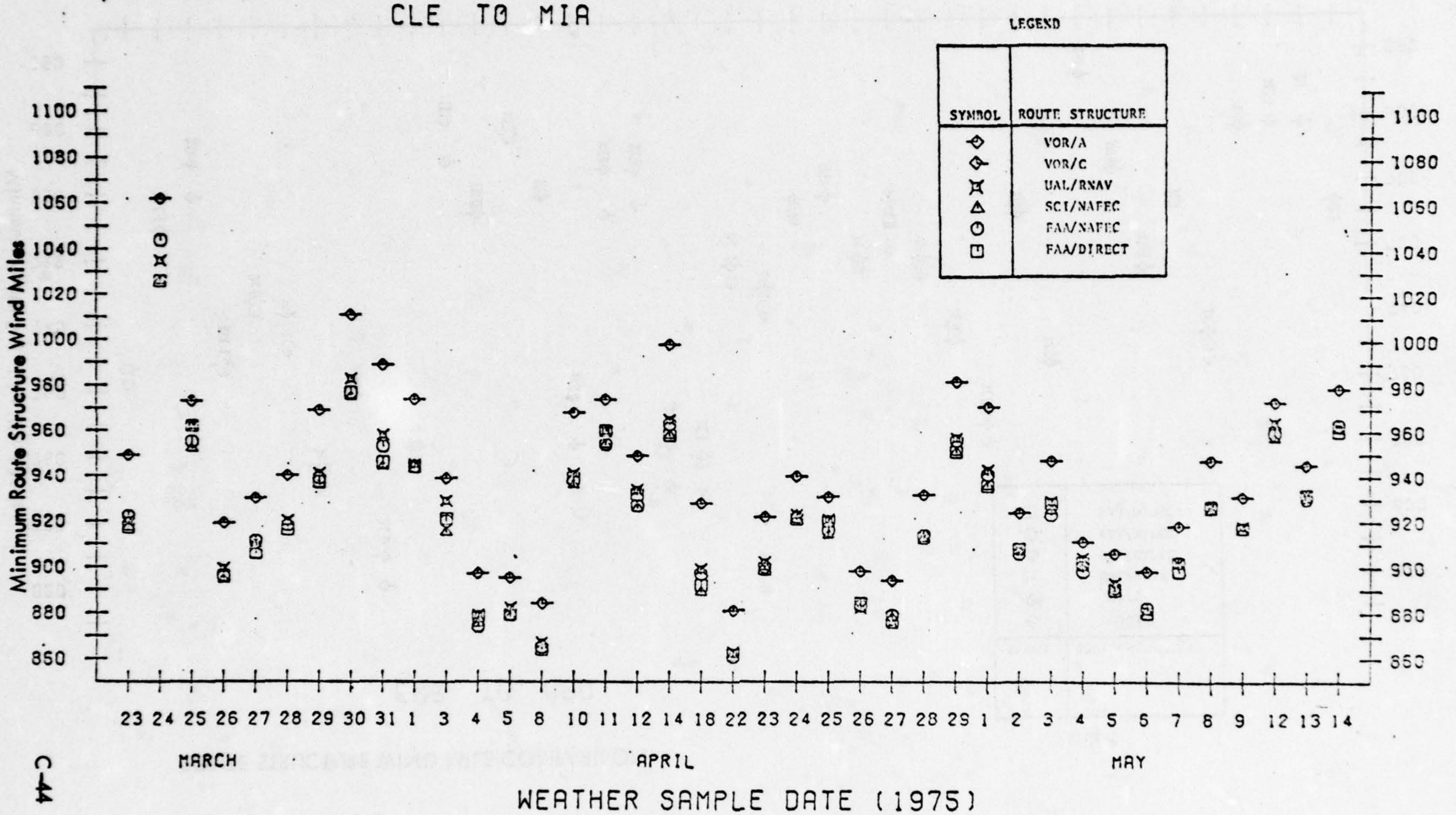
ROUTE STRUCTURE WIND MILE COMPARISON

EWR TO ORD

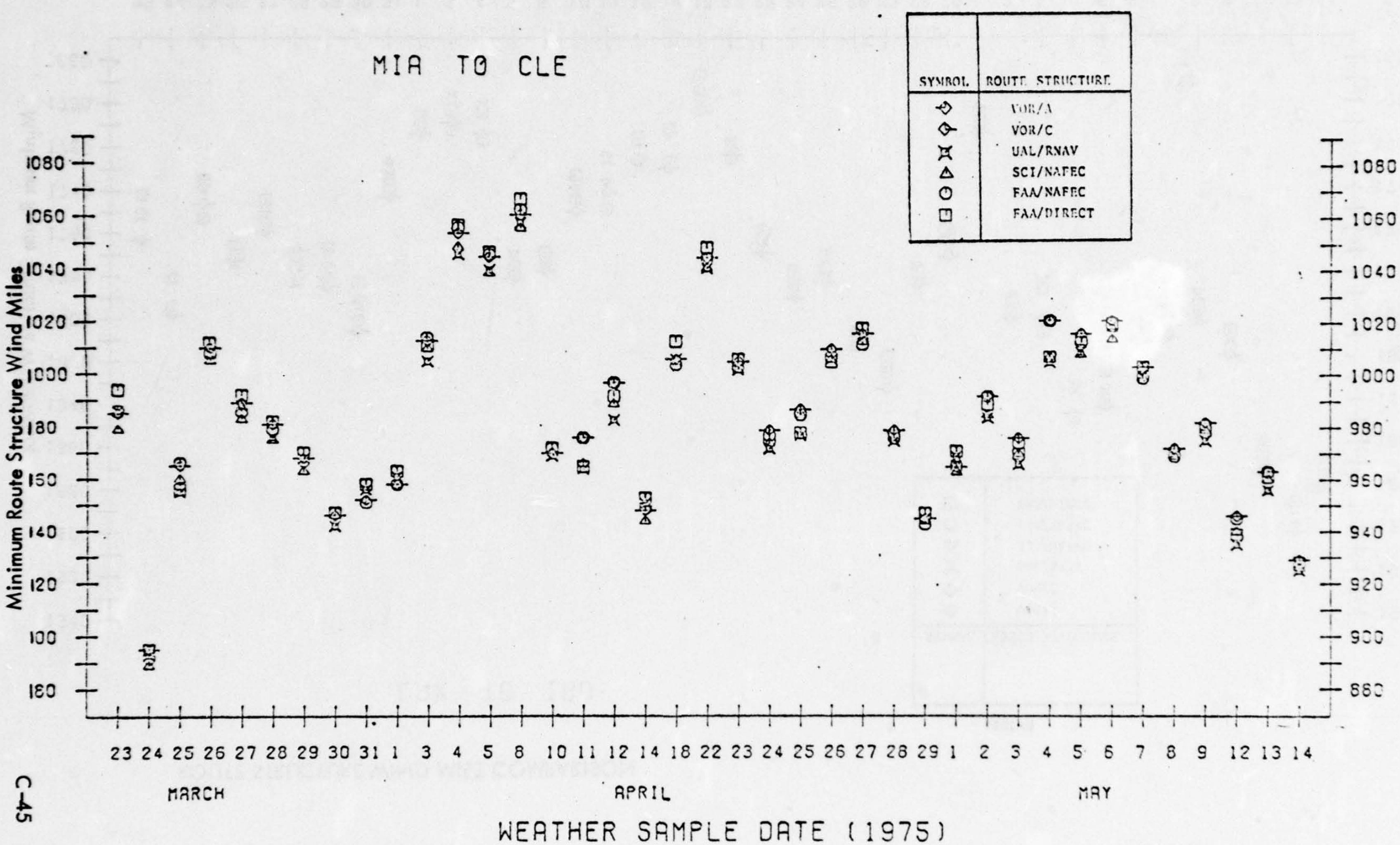


ROUTE STRUCTURE WIND MILE COMPARISON

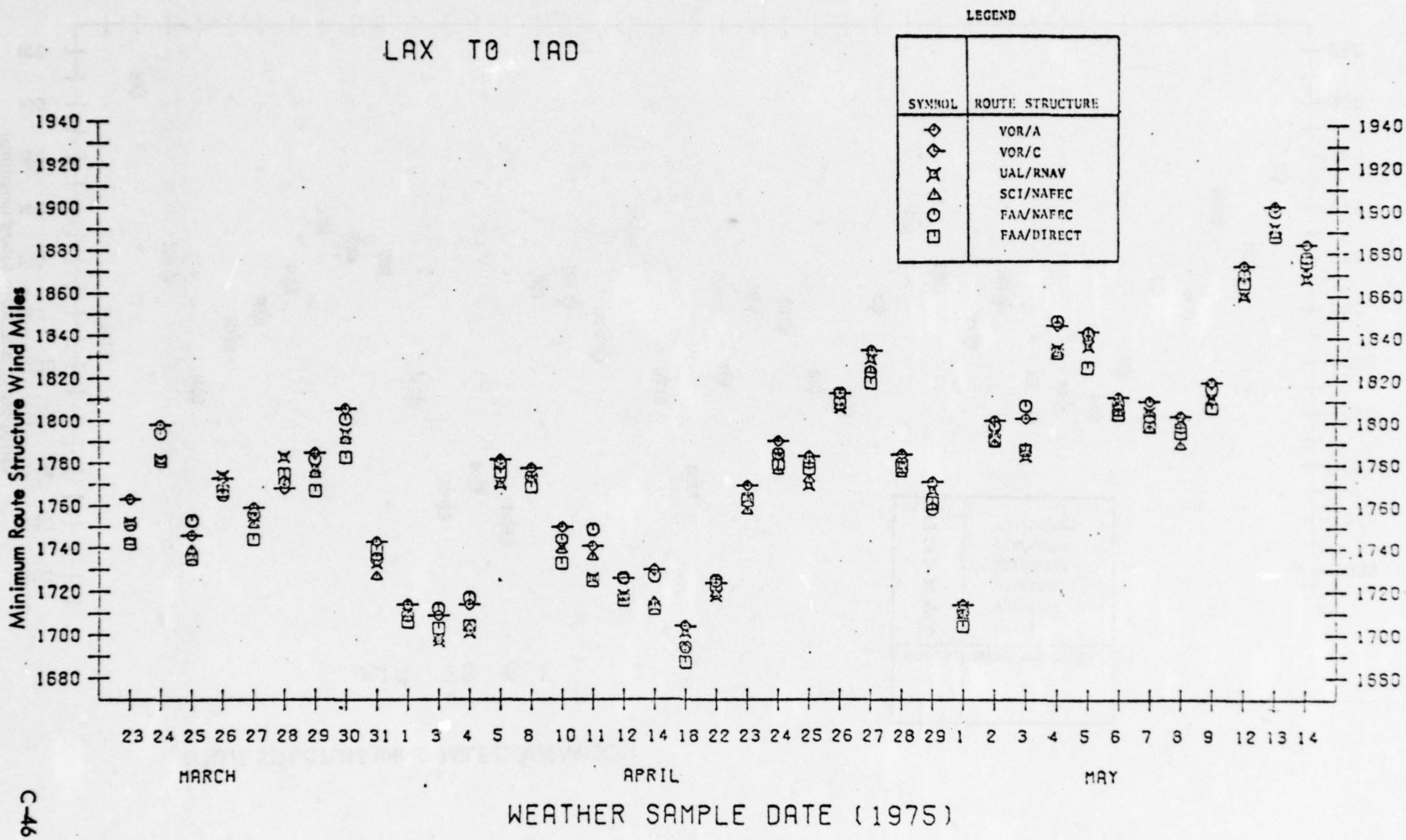
CLE TO MIA



ROUTE STRUCTURE WIND MILE COMPARISON



ROUTE STRUCTURE WIND MILE COMPARISON



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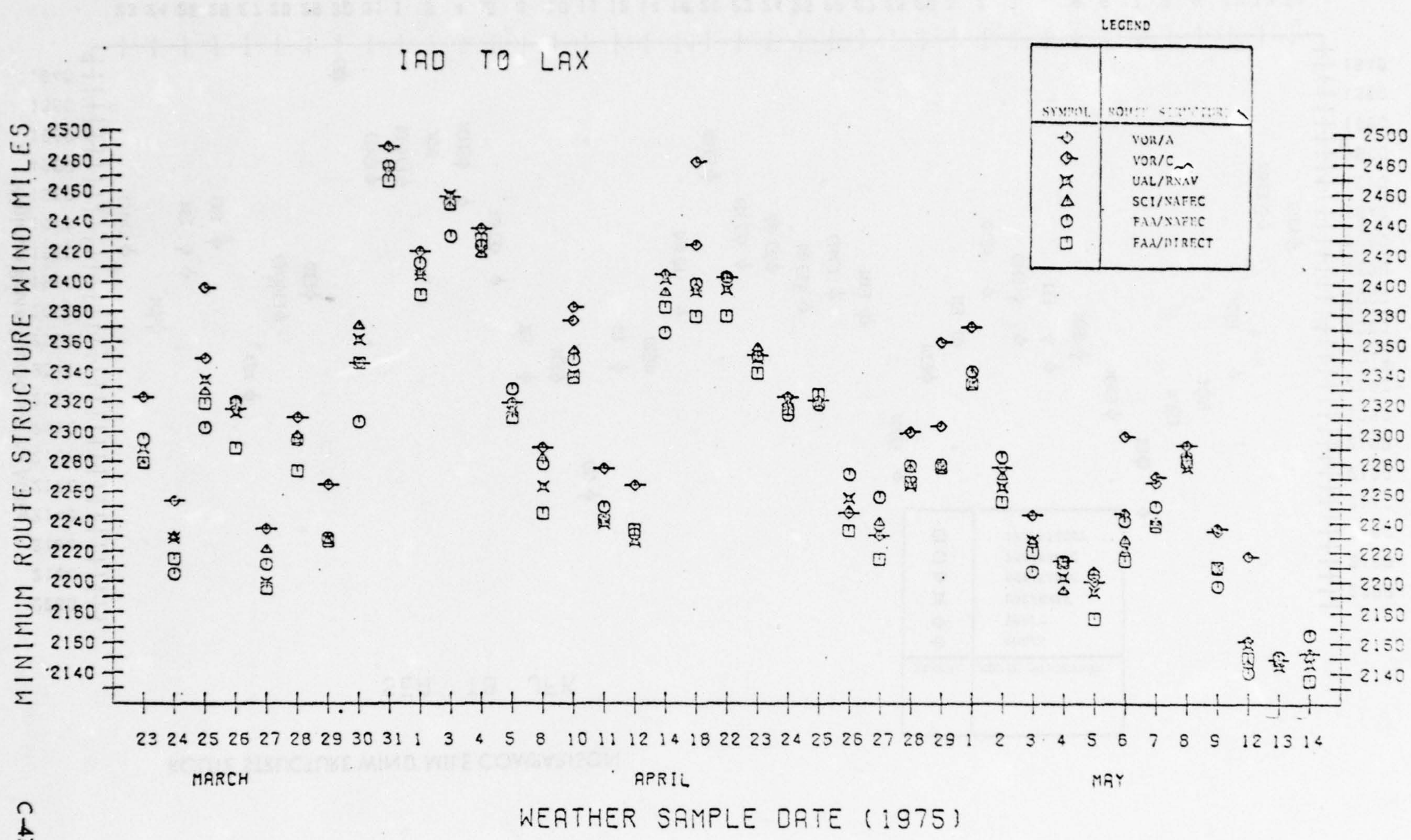

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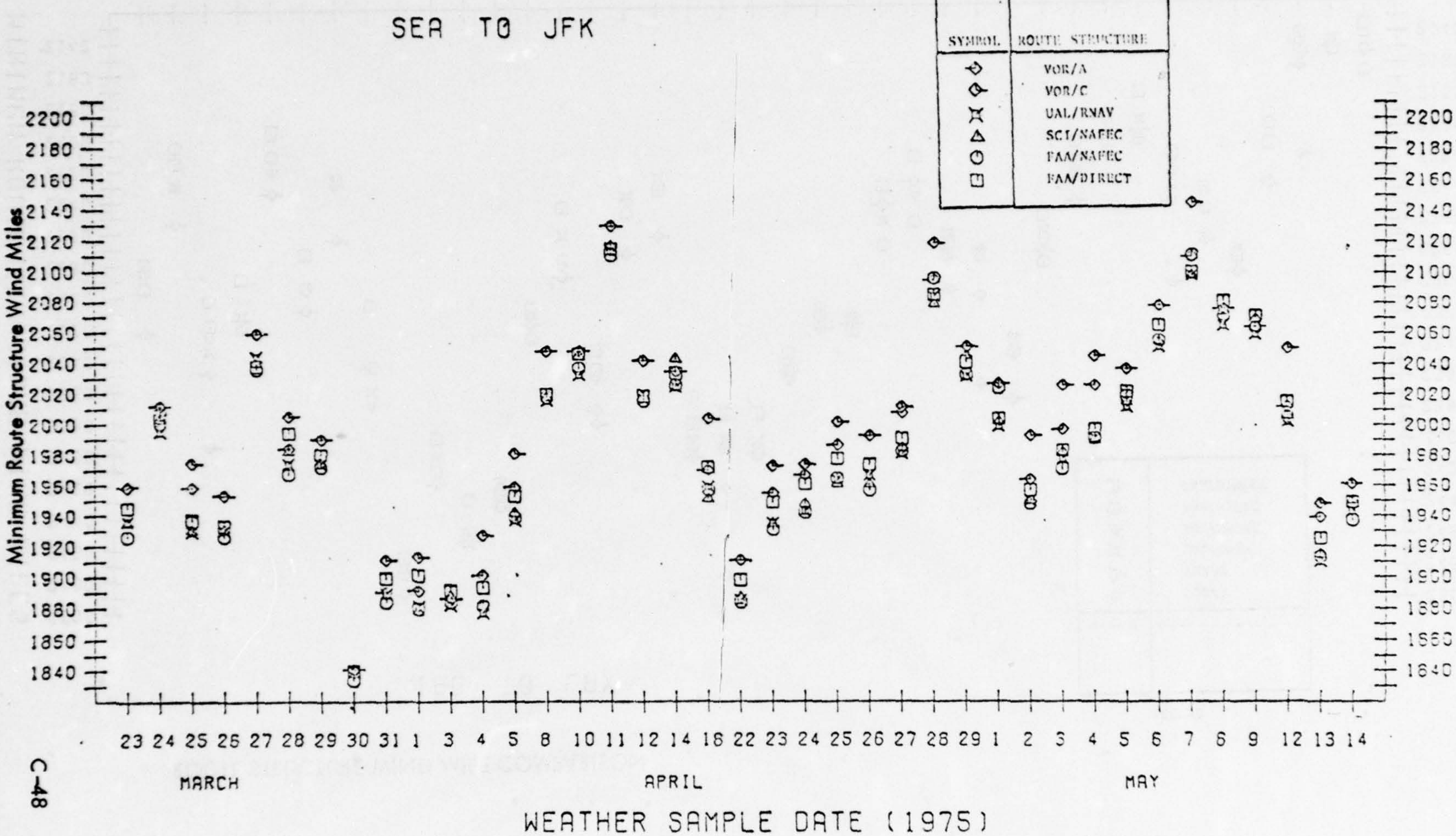

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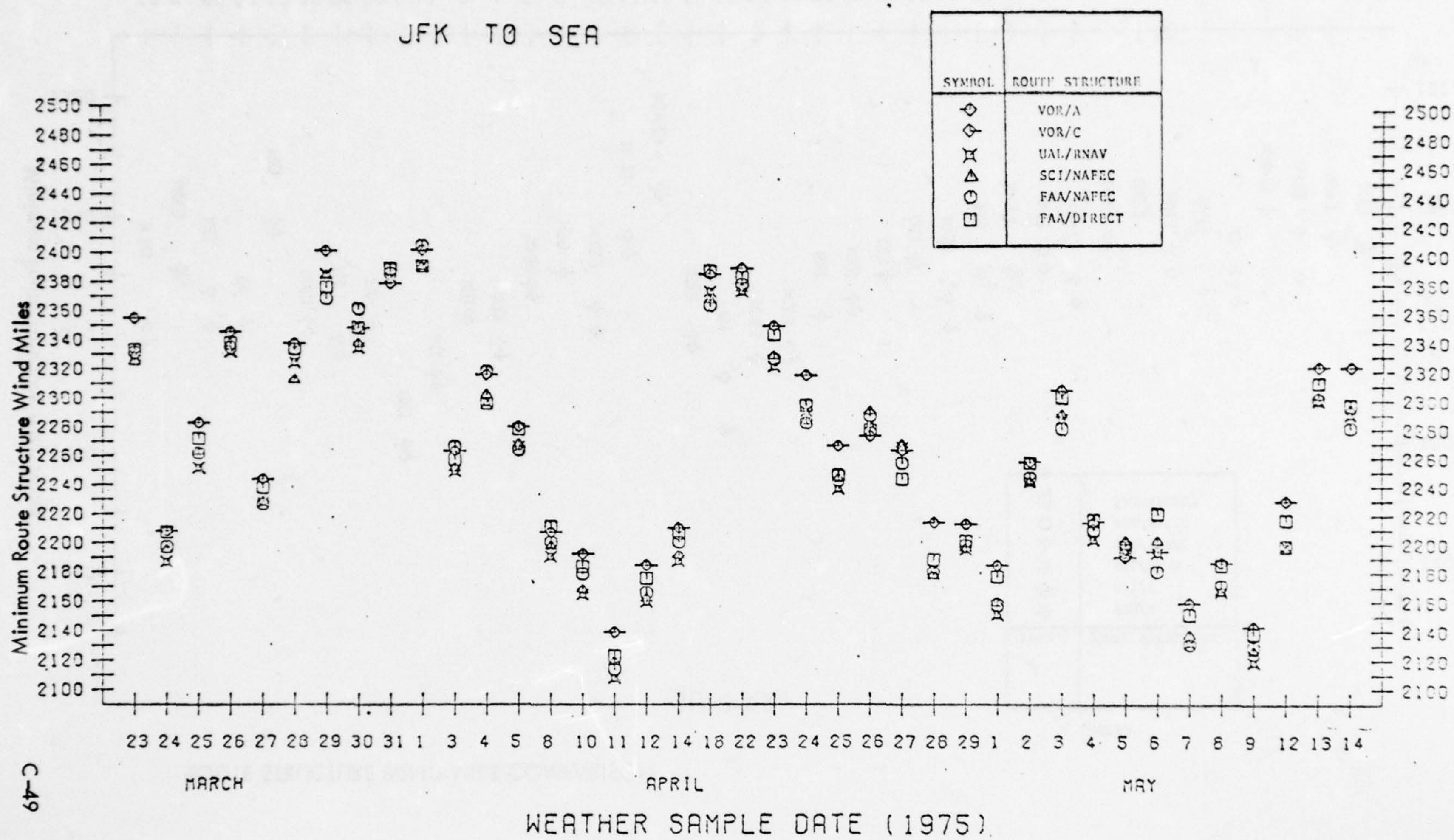
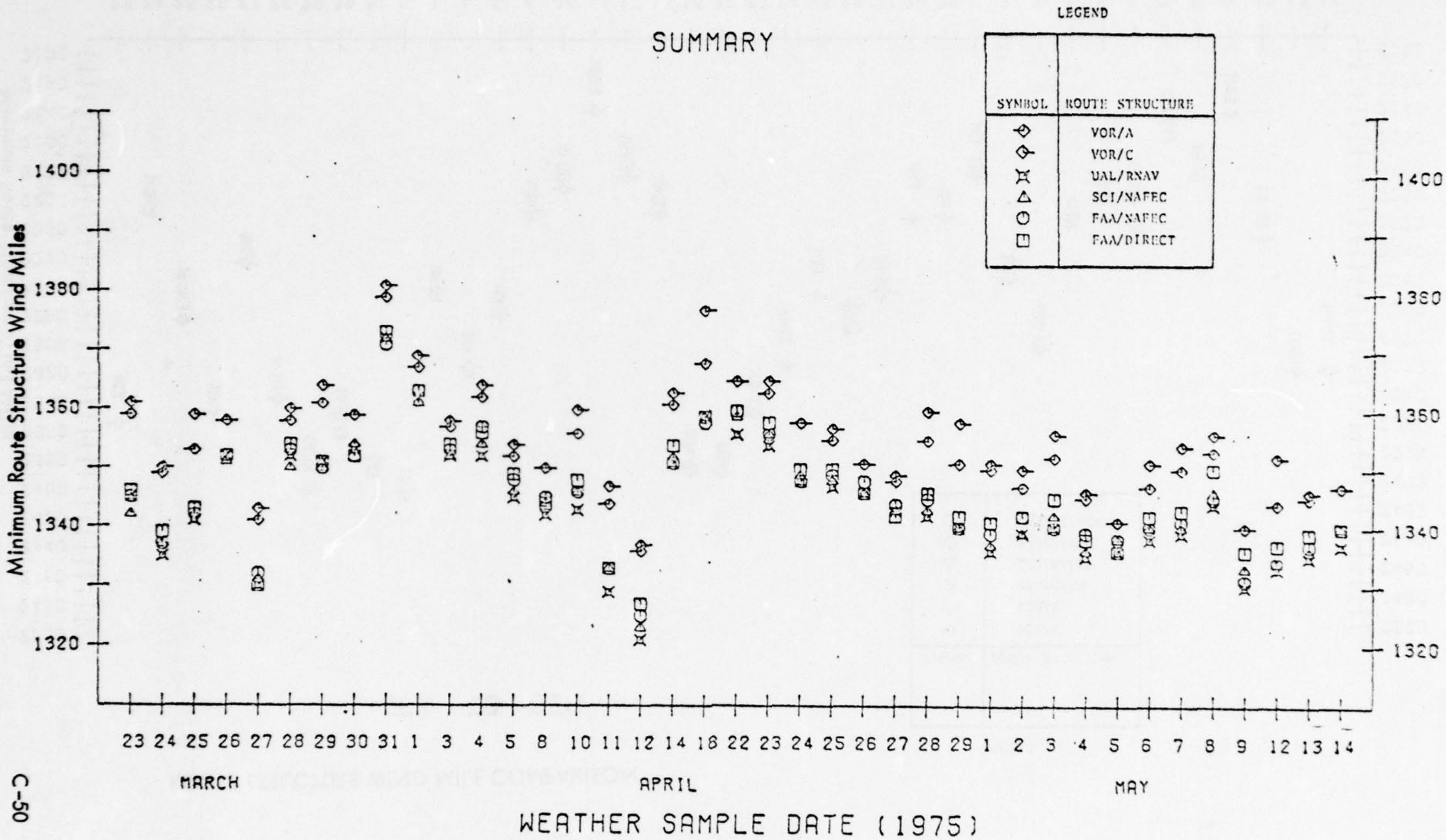


ROUTE STRUCTURE WIND MILE COMPARISON

SUMMARY



APPENDIX D

Development of Regression Model For Low Altitude Route Length Benefits

Implementation of a regression analysis, in its common form, simply involves the least squares fitting of a multidimensional plane to sets of independent variables. When only one independent variable exists, the end result is simply the fitting of a least squares straight line to estimate the linear relationship between the dependent and independent variables. In multivariable cases, the line is replaced by a linear model or hyperplane. The basic model is as follows:

$$Y - c + b_1X_1 + b_2X_2 + \ldots + b_mX_m$$

The variables $X_1,\ldots,X_m$ are referred to as independent variables, while Y is the dependent variable. The relationship between the dependent variable and the independent variable is assumed to be as given above and the estimation of the constant c and the coefficients $b_1,\ldots,b_m$ is the objective of the regression analysis. The solution to the regression problem is the set of values $\hat{c}$, $\hat{b}_1,\ldots\hat{b}_m$ which minimizes the error sum of squares over a given sample. The error sum of squares is defined by

$$E = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$

where

$$\hat{y}_i = \hat{c} + \hat{b}_1 X_{1i} + \hat{b}_{2i} + \ldots + \hat{b}_m X_{mi}$$

and the i subscript denotes the ith sample.

The solution of the coefficient values follows readily from matrix theory. The reader is referred to Reference 64 for any of the relevant details. Regression analysis need by no means be confined to the consideration of linear models. The most expedient way to address monlinear models is to include additional independent variables which are nonlinear combinations of the original independent variables. A quadratic equation can be fitted simply by including a second set of independent variables which are the squares of the first set.

In general, many regression models can be used to characterize a given set of data and some means to establish their relative merit is necessary. A common and favored approach is to compare the regression error sum of squares to the sum of squares of the deviations from the mean. By definition, the sums of squares of the dependent variables about their mean is the minimum over the sums of the squares about any other constant. Assuming that one is concerned with minimizing the expected square of this estimation error, the comparison of the two error sums of squares, therefore appropriately measures the ability of the regression model to reduce the error. The following definitions are useful:

Let

$$E_B = \sum_{i=1}^{n} (y_i - \bar{y})^2$$

$$E_A = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$

What is referred to as the "total regression coefficient" can now be written as:

$$R = \sqrt{\frac{E_B - E_A}{E_B}}$$

This measures the proportion of the variance, or error sums of squares, which is eliminated through the use of the regression model. The term, R, is also algebraically identical (except for the sign) to the correlation coefficient between the dependent variable and the resulting regression estimates.

Finally, if there are as many variables as samples, the error sums of squares can invariably be reduced to zero. This occurs in the same manner that a line can always be fit through two points, a plane through three points, etc. A total regression coefficient of units would result, which should obviously not be construed to imply perfect validity of the regression model. In a similar manner, the inclusion of an additional variable will result in an error sum of squares never greater than the previous amount. Thus, the addition of a set of random numbers as another independent variable produces a better regression fit and it is the responsibility of the analyst to understand that the regression model has in fact been degraded rather than improved. Fortunately, there are a variety of statistical tests designed to distinguish between a random improvement due to a statistically justifiable correlation. The technique applied in this study is referred to as a "stepwise selection procedure". This procedure essentially accepts or rejects independent variables from the model depending upon whether or not they reduce the error sums of squares by an amount significantly greater than that which would be expected by randomness alone. The specific significance level used on a given run must be stipulated by the analyst.

The twelve independent variables described in Section 3.3., in combination with the route length results of the design effort, was the fundamental data base used in this regression analysis. It is apparent that there are a great many potential regression models which can be derived from these data. In order to converge upon a satisfactory model in an expeditious and cost-effective manner, the regression attempts were designed to achieve the following;

1) Determine the most suitable dependent variable and the independent variables which contribute most significantly to the regression fit.

2) Determine the improvement in the regression fit of nonlinear variations of the significant variables.

3) Compare the resulting models and select that which is the most appropriate.

Within the first set of regression attempts, three dependent variables were analyzed; the RNAV Absolute Mileage Benefit, the Percent Benefit and the Flight Mile Benefit. Many regression fits were made for each dependent variable. The runs of particular importance were those wherein all independent variables were forced into the model and those where very high levels of significance were used to select the variables. Forcing all variables into the model provides the best possible linear regression fit, while the stepwise approach provides the regression fit which can be statistically justified. It was found that the level of significance of the statistical tests did not play a major role in the model results. Variables which were correlated to the dependent variable at all were highly correlated. Statistical tests using lower levels of significance did not often result in the inclusion of additional dependent variables. Unless otherwise stated, the significance levels used were .05/.10. This implies that no variable was entered unless its improvement to the model was significant at the 95% level and included variables were rejected whenever the inclusion of more important variables caused their incremental improvement to drop below the 90% significance level.

The results of this first set of runs are summarized by a subset of runs, specifically 1 through 9 of Table D.1. From these results, it was apparent that the dependent variable, RNAV Absolute Benefit, would provide the best results. The Flight Mile Savings were virtually useless, which basically indicates a lack of correlation between the exchange rate and either the suitability of the VOR route or the RNAV benefit. The Percent Benefit was eliminated from further consideration since its results were poorer than those produced when using the Absolute Benefit, even at lower significance levels.

The stepwise procedure for the Absolute RNAV Benefit resulted in the inclusion of only three variables; the airports in the terminal areas, the airports overflown and the great circle distance. At no significance level down to and including .40/.50 was any other variable entered.

The second set of regression attempts were designed to determine whether or not certain nonlinear variations would provide better results. The variables previously included were the only ones upon which nonlinear variations were used. Specifically, the squares and square roots of each of these variables were added to the data set, in separate runs. In each case, a marked improvement was obtained culminating in Runs 10 and 11 of Table D.1, both of which produced a regression coefficient of .49.

Table D.1

Run No.	Dep. Var.	Dep. From Both Terminals	Airports Overflown: No. of = O	O²	√O	Dep. From	Great Circle Distance: G	G²	√G	Intersections: No. AP Pairs	Intersections: No. Flts.	AP Pair Exchange	Number of Airports Within Terminal Area: Total: A	A²	√A	Lesser No.: A_s	A_s^2	Greater No.: A_L	A_L^2	Dep. From Airports Within Terminal Area: Total	Lesser No.	Greater No.	Significance Level	Total Regression Coefficient
1	F	1	1			1	1			1	1	1	1							1			F	.37
2	F	0	0			0	0			0	0	0	0							0			.05/.10	0
3	F	0	0			0	0			0	0	1	1							0			.10/.20	.27
4	F	1	0			0	0			0	0	1	1							1			.40/.50	.33
5	P	1	1			1	1			1	1	1	1							1			F	.45
6	P	0	1			0	0			0	0	0	1							0			.05/.10	.40
7	A	1	1			1	1			1	1	1	1							1			F	.48
8	A	0	0			0	1			0	0	0	1							0			.05/.10	.43
9	A	0	1			0	1			0	0	0	1							0			.10/.20	.46
10	A	0	1	0		0	1	0		0	0	0	1	1						0			.05/.10	.49
11	A	0	1		0	0	0		1	0	0	0	0		1					0			.05/.10	.49
12	A	0	1	0			1	0		0	0	0				1	0	1	0		0	0	.05/.10	.49

Significance level of F implies that the variables were forced into the model; significant testing was not done. Zero entries imply that these variables were available for selection but were not included at the stated significance level. One entry implies that those variables were utilized in the resulting regression equations.

Dependent Variables: F = flight mile benefit; P = percent benefit; A = absolute route mile benefit

The last regression model which was explored evolved by treating the airports (and departures) of each terminal area as separate characteristics rather than using only their respective sums. These data were ordered so that the area with the fewer airports was listed as one independent variable; the area with the greater number listed as the other. This allowed the regression model to make a distinction between whether or not the airports were evenly distributed between the two terminal areas. The results were highly useful in that they produced a regression coefficient of .49 (at a .05/.10 significance level) and as shown by Run 12 of Table D.1, which included the following variables:

1) The number of airports in the less dense* terminal area

2) The number of airports in the more dense area

3) The number of airports overflown

4) The great circle distance

Also of interest was the fact that the nonlinear variations which previously provided substantial improvements no longer did so. Even though available, they were not entered into the model at any significance level.

This model (Run 12) was favored over the two nonlinear models previously mentioned (Runs 10 and 11), even though the regression coefficients were the same. The linearity of the latter model provided more intuitive appeal. Equal results were obtained at equal levels of significance, thereby precluding further mathematical or statistical means as a method of defining the preferred regression model.

Thus, the final regression model (12), was selected for subsequent use in estimating, on a national scale, the potential RNAV low altitude benefits. Its parameter values are as follows:

$$\hat{R}_B = C + B_1 \cdot A_S + B_2 \cdot A_L + B_3 \cdot \theta + B_4 \cdot G$$

where

A_S, A_L: number of airports in the terminal areas, 25 nm radius ($A_S \leq A_L$)

θ : number of airports overflown (within 25 mi of the great circle arc)

G : great circle distance

$\hat{R}_B$: estimated RNAV absolute mileage benefit

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*Less dense implying fewer airports

and $C = 4.058$
$B_1 = -1.455$
$B_2 = -0.285$
$B_3 = -0.428$
$B_4 = 0.031$

An assessment of this model reveals that the "average" RNAV route in the California design produced a route length benefit of 3.96 nm. The regression results imply that RNAV produces a constant 4.06 nm benefit component which, being constant over all routes, would be attributed to an improved RNAV terminal/enroute interface capability. RNAV also produces a maximum route length benefit component of 3%, relative to a "worst case" VOR route (barring extremes), of the route length (great circle distance). This RNAV benefit is reduced as when the actual VOR routes are shorter than what was referred to as worst case. Specifically, when many airports exist in either of the terminal areas and/or when many airports are overflown, the model indicates that better than average VOR routes tend to exist. Initially, these airport-oriented characteristics were included so that degradation of the RNAV routes could be explained within the model. In retrospect, the predominant factor is the proliferation of VOR stations, and consequently the opportunity to design better than average VOR routes in areas where many terminals exist. Degradation of the RNAV routes is only a secondary effect which occurs only when the VOR structure is so complex that RNAV routes must be designed coincident with the VOR. The model produces large RNAV benefits in desolate areas and small benefits in high density areas, which is consistent not only with the results of the California design but also with what is intuitively expected elsewhere.

While the regression results are reasonable and interpretable, the total regression coefficient was lower than desired. In order to estimate an ultimate upper bound on the regression coefficient, and thereby judge the success of this effort, a final regression attempt was made wherein the actual VOR route lengths were used as an additional independent variable. The only unexplainable variation remaining for the regression model to address was, therefore, the RNAV route lengths. The resulting total regression coefficient of .86, lower than expected, can therefore be considered an upper bound. Computation of the VOR route length for all 8,000 airport pairs was logically not a practical approach. Since no set of independent variables would ever be expected to provide a perfect estimate of the VOR route lengths, the inclusion of more sophisticated variables would probably not have resulted a regression coefficient greater than about 0.7. The achieved regression coefficient of .49 is therefore not too far below that which could be attained even if computational limitations did not exist. Further, the four pertinent variables were included at a very high significance level.

The relationship between the RNAV benefits and the airport pair characteristics used with the model are statistically justified for routes within California. There is no reason to believe that the general validity of the model is not adequate when applied to other regions of the country.

APPENDIX E

SLANT RANGE ERROR FLIGHT TEST PROGRAM

Introduction

This appendix presents the test plan and resulting aircraft track plots (Figures E.5 through E.13) of the RNAV slant range error effect flight test program. The objective of the slant range error flight test is to determine what effects uncompensated slant range error has on achieved flight paths and airspace requirements in terminal area operations. In order to make this determination, four profiles at two altitudes have been designated for test purposes. The primary criteria defining these paths were to locate the point of closest approach to the VORTAC station either on a line of 45° elevation or 60° elevation with respect to the horizon, and to make the flight paths long enough to allow stabilization of the aircraft on the nominal flight path before entering the region where the slant range effect is felt. The altitudes selected are 8000 feet and 12000 feet. The lower level was selected because previous experience (Baseline Flight Test) [7] indicates that the effect is unnoticeable at lower altitudes. The higher altitude was selected as being a reasonable boundary on terminal area operations, particularly for GA aircraft which would typically have lower-capability RNAV equipment.

Test Plan

Because of convenience, the Miami ARTS III TRACON was selected for the flight test site. There are two VORTACs in the Miami area, Miami and Biscayne Bay. Miami VORTAC is surrounded by busy airspace, and so was discarded. Biscayne Bay, several miles South of the airport, is relatively free of traffic. An East-West course was selected since very little interfering traffic exists at the selected altitudes. The flight test profiles are defined in Table E.1, and depicted graphically in the attached navigation charts (Figures E.1 through E.4).

In order to bound the expected slant range effect, two subject pilots were selected to fly the profiles. The first was not advised of the purpose of the test, but was instructed to fly as he normally would. The second subject was aware of the purpose of the test and followed the RNAV guidance signal as closely as possible within reason considering normal maneuver restrictions and passenger comfort limitations. In this manner, the slant range effect to be expected given any typical pilot was included between the bounds defined by the two subject pilots. Each pilot flew each of the four profiles twice in order to provide adequate data.

The navigation signals were instrumented using a strip chart recorder in much the same manner as in the Denver and Miami flight tests ("Initial RNAV Operational Test Plan, Miami Area", June 12, 1974, Champlain Technology, Inc.). In addition to cross track deviation, distance to waypoint, time and transponder IDENT signal, three additional signals (DME range, TO/FROM flag and CDI Valid flag) were recorded. In particular, the DME signal was important since this was a slant range error test. The CDI flag was used for determining the extent of the zone of confusion around the VORTAC.

Data recovery and processing was conducted in the same manner as in the earlier flight test programs. Modifications to the merge and statistical analysis programs were required in order to properly process the DME measurement.

Table E.1 Flight Profile Data

Altitude	Elevation Angle	Tangent Point Dist.	Slant Range Error	Waypoint Name	Rho	Theta	Latitude	Longitude
8000 ft	45°	1.317	0.55	Johnson	10.1	97.5°	25° 38' 58"	79° 59' 36"
				Elliott	10.1	262.5°	25° 38' 58"	80° 21' 44"
	60°	0.760	0.76	Pancho	10.0	94.3°	25° 39' 32"	79° 59' 38"
				Bolz	10.0	265.7°	25° 39' 32"	80° 21' 41"
12000 ft	45°	1.975	0.82	Adams	10.2	101.2°	25° 38' 18"	79° 59' 36"
				McConkey	10.2	258.8°	25° 18' 18"	80° 21' 43"
	60°	1.140	1.14	Richardson	10.1	96.5°	25° 39' 08"	79° 59' 34"
				Clark	10.1	263.5°	25° 39' 08"	80° 21' 46"

Figure E..1 TERMINAL RNAV PROCEDURE TEST

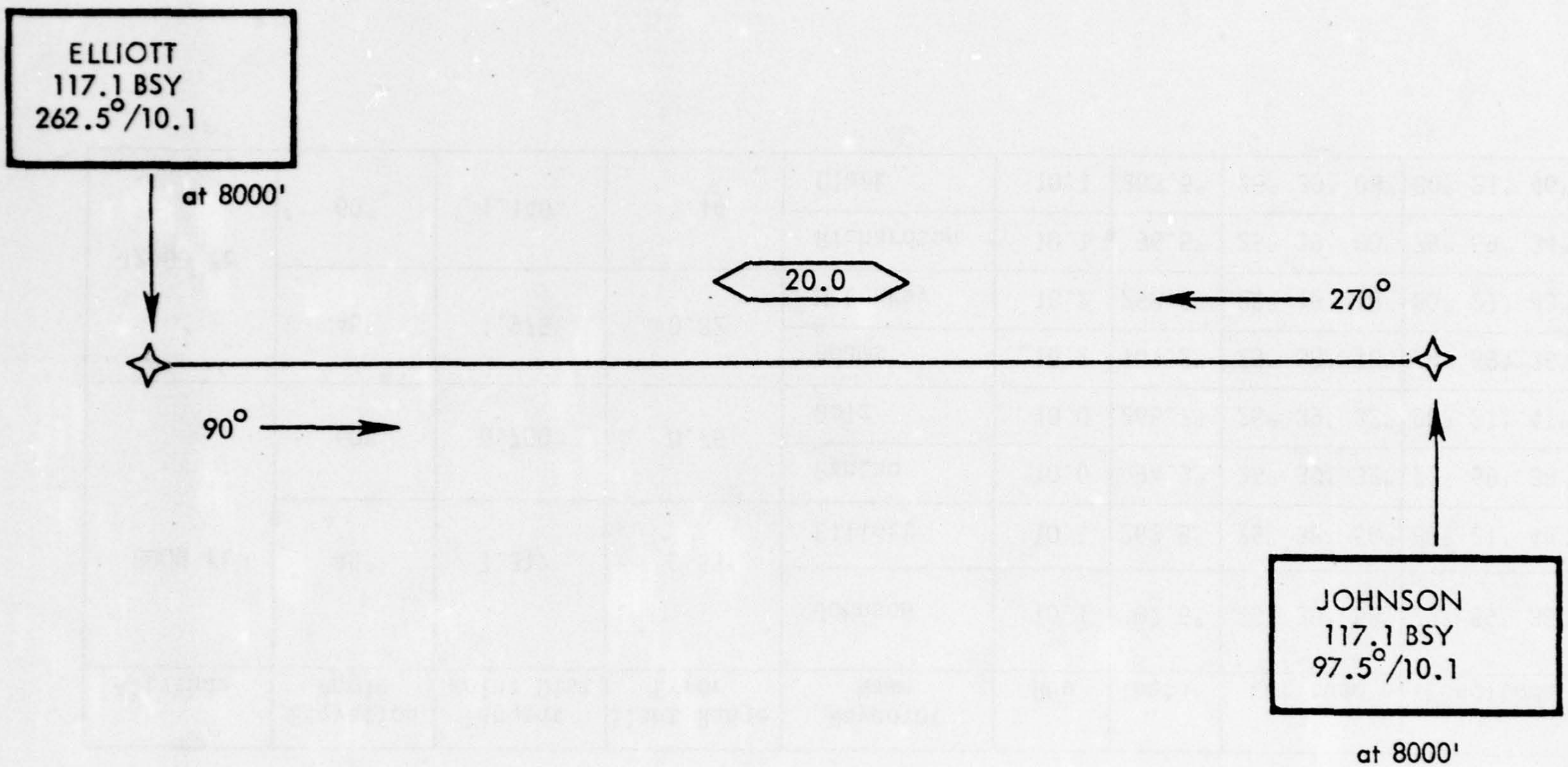


Figure E.2 TERMINAL RNAV PROCEDURE TEST

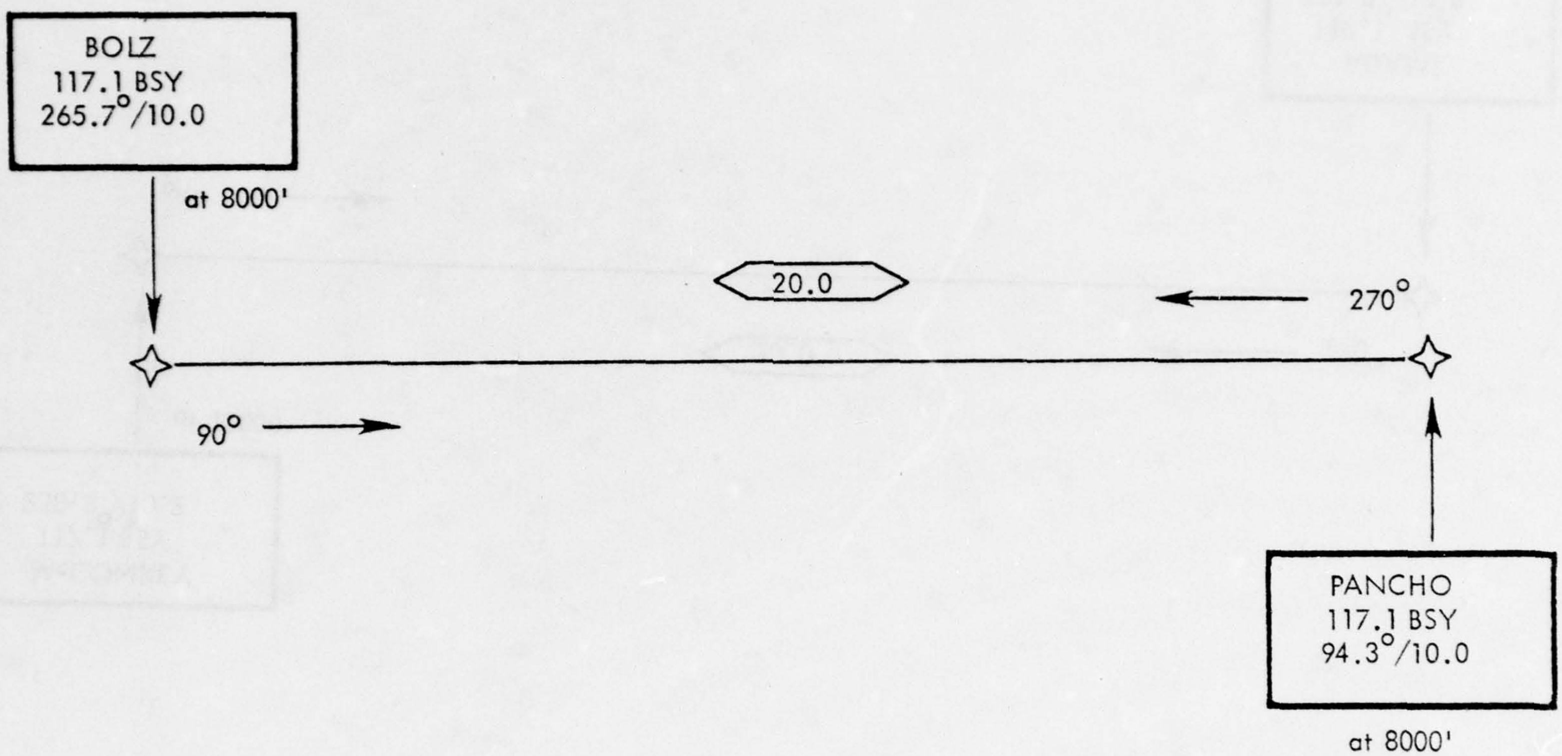


Figure E.3 TERMINAL RNAV PROCEDURE TEST

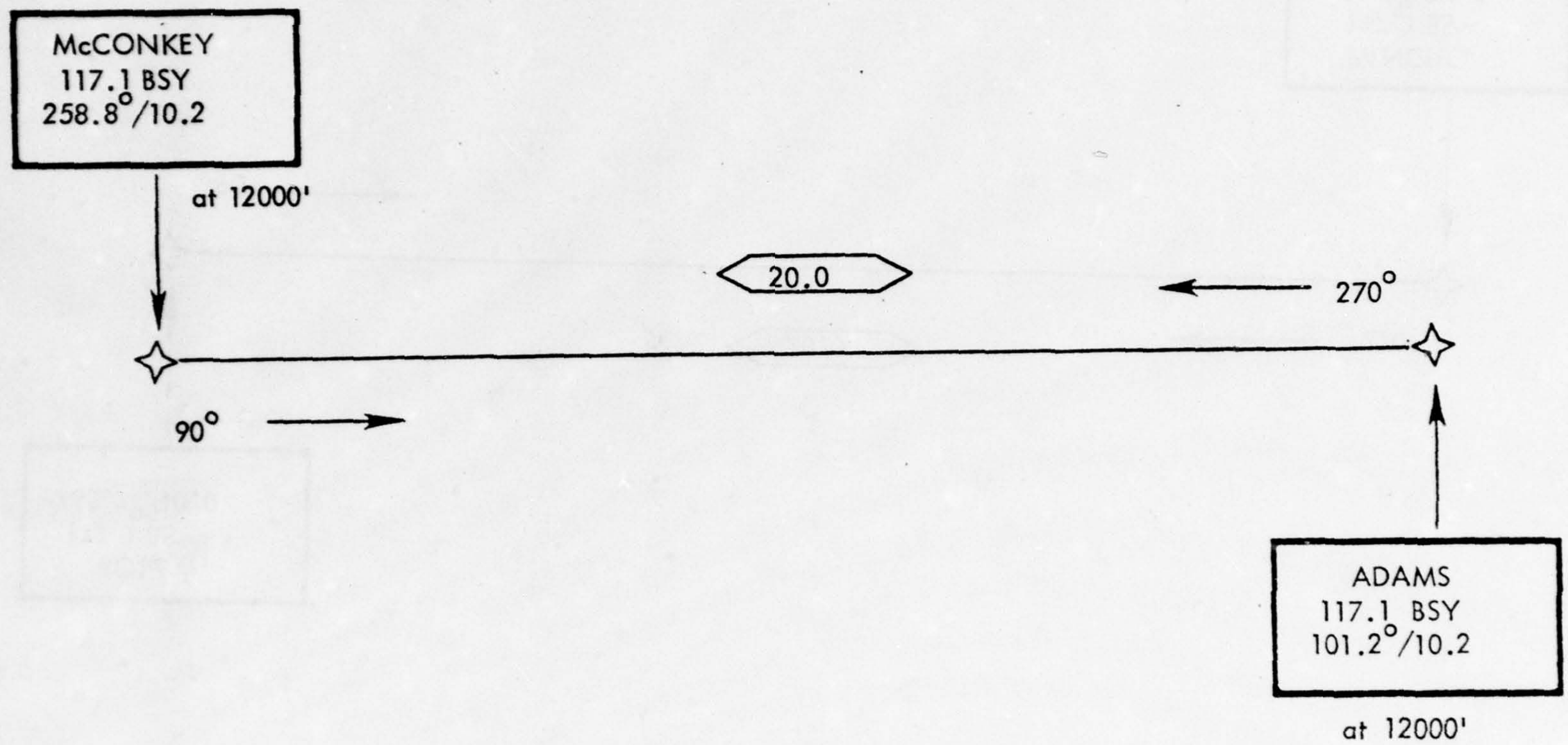
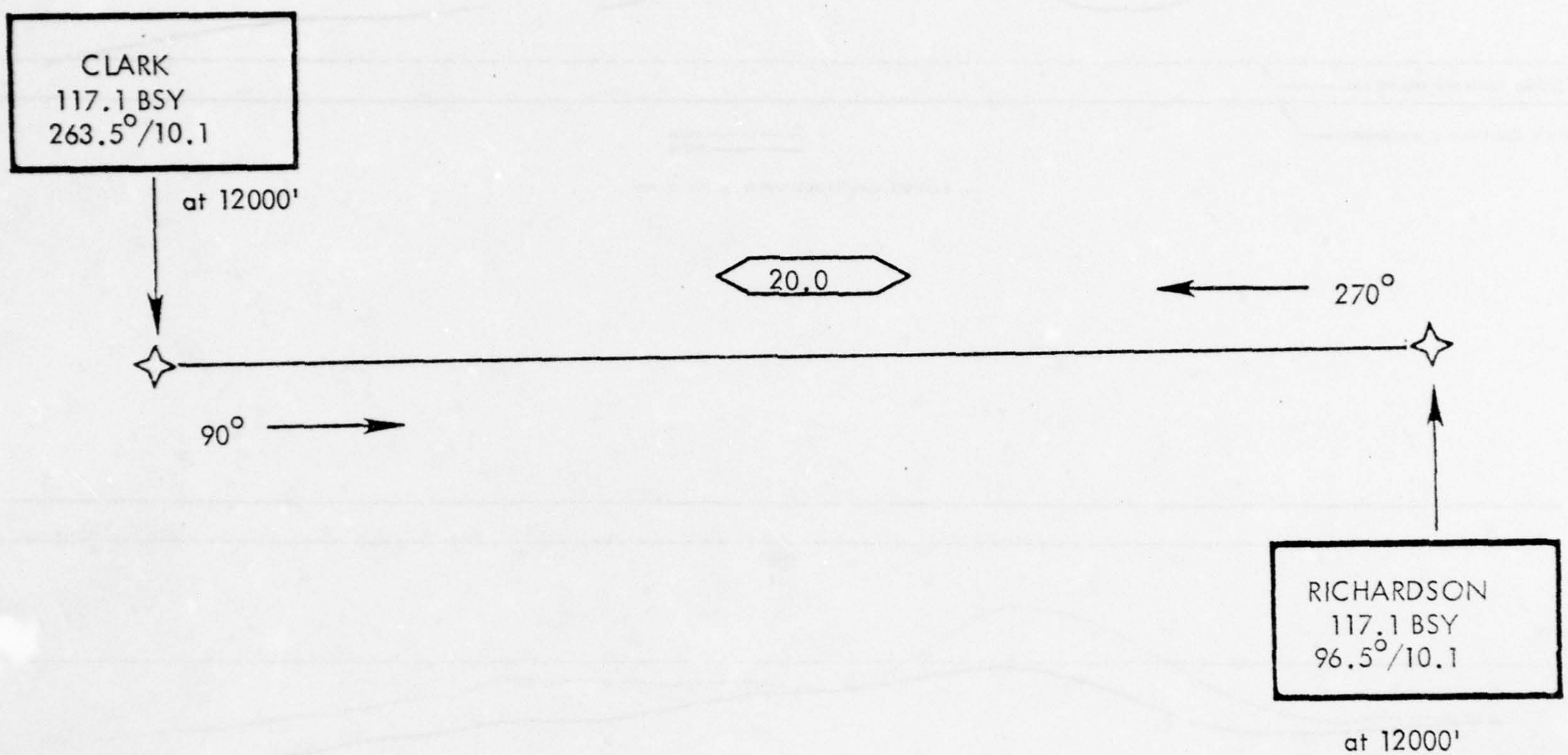


Figure E.4 TERMINAL RNAV PROCEDURE TEST



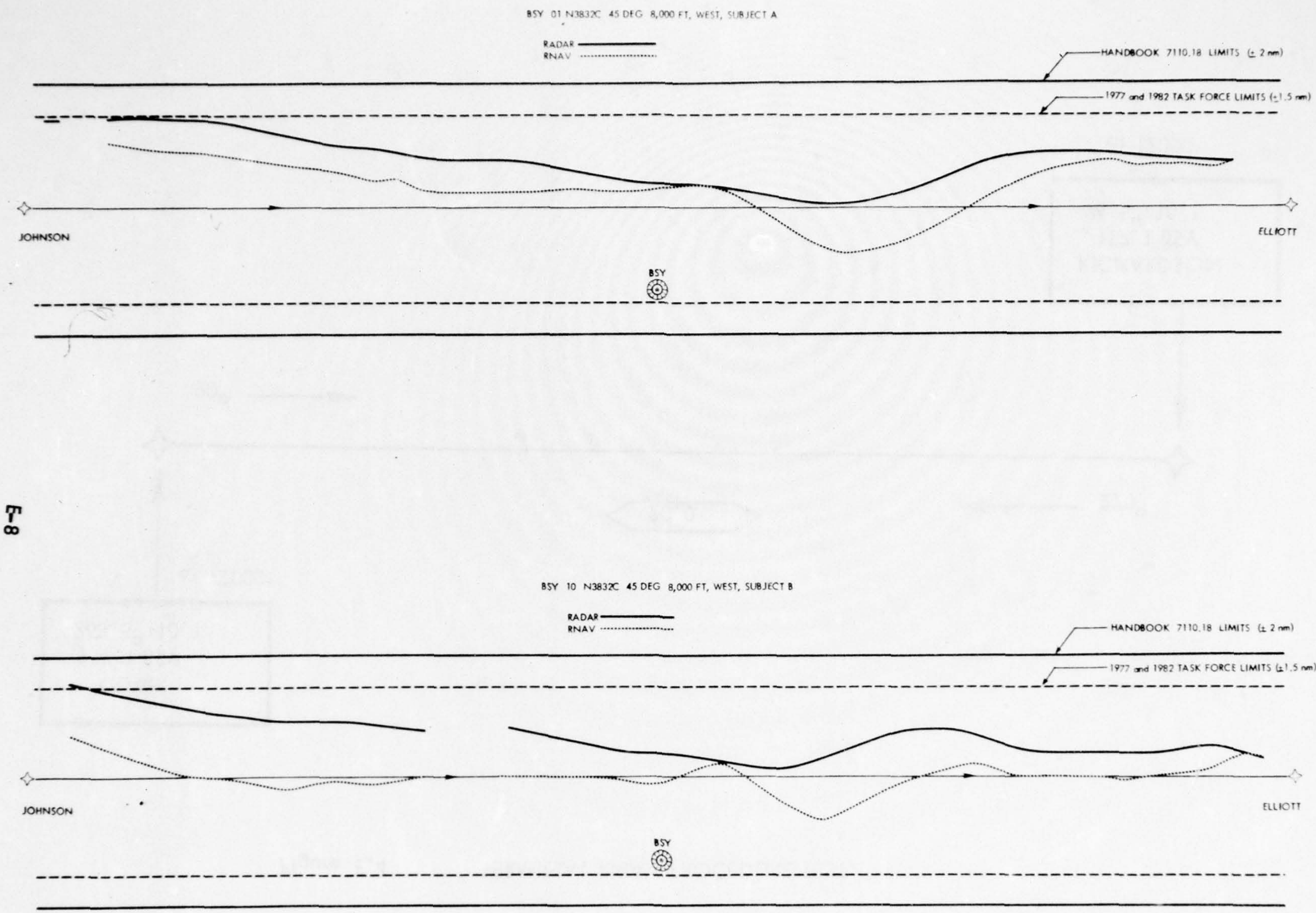


Figure E .5 SLANT RANGE ERROR FLIGHT TEST RESULTS

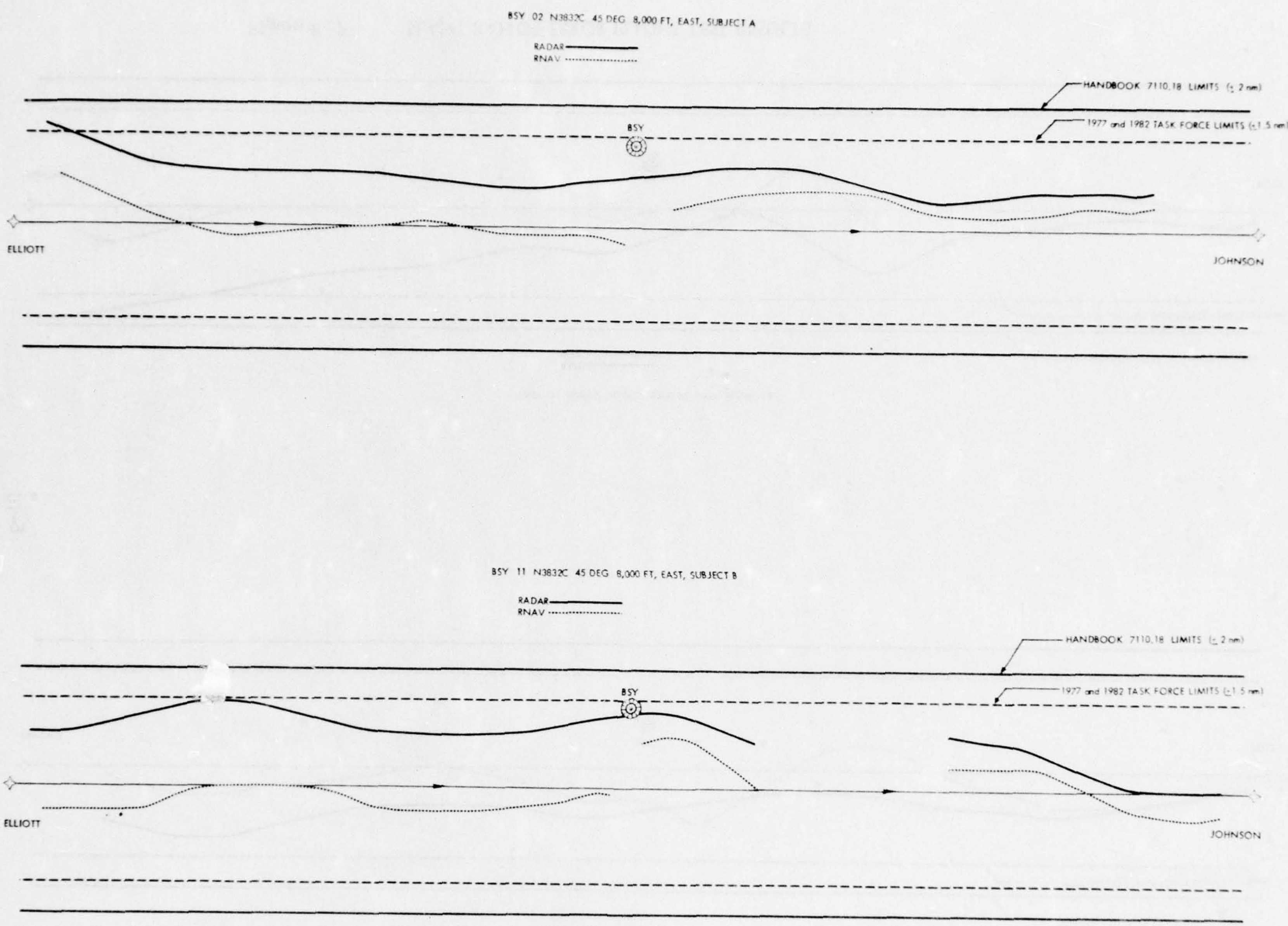


Figure E.6 SLANT RANGE ERROR FLIGHT TEST RESULTS

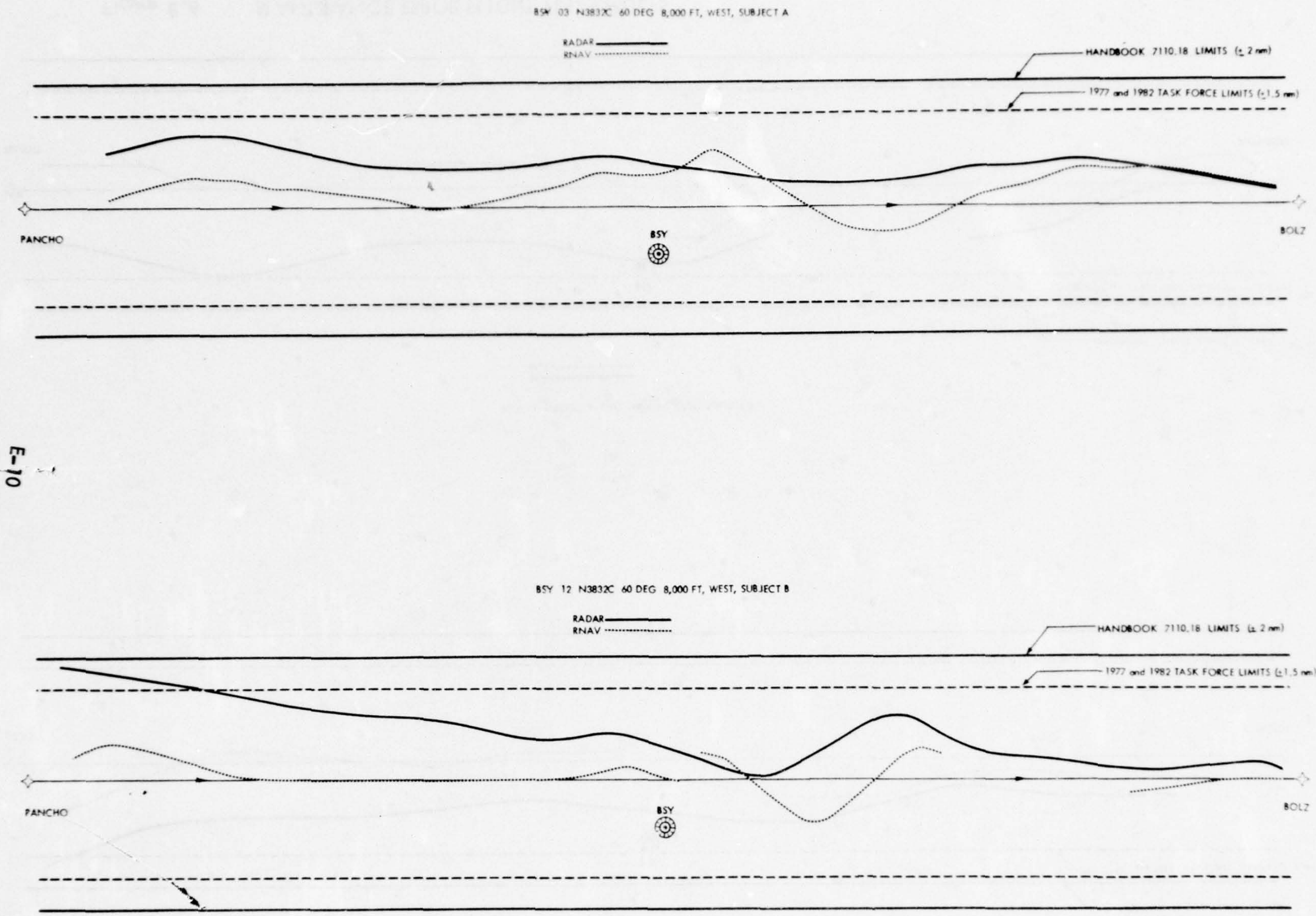


Figure E.7 SLANT RANGE ERROR FLIGHT TEST RESULTS

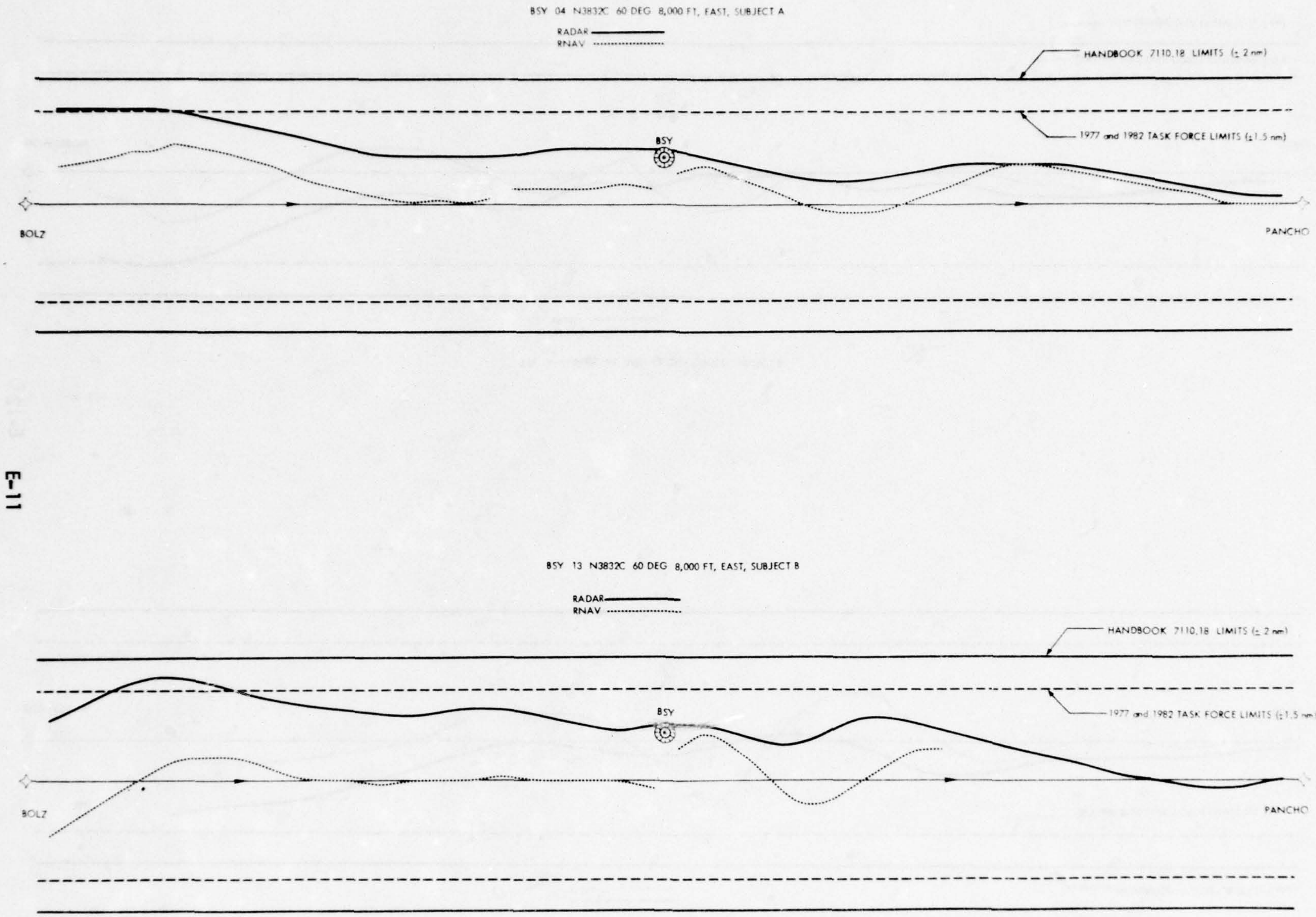


Figure E.8 SLANT RANGE ERROR FLIGHT TEST RESULTS

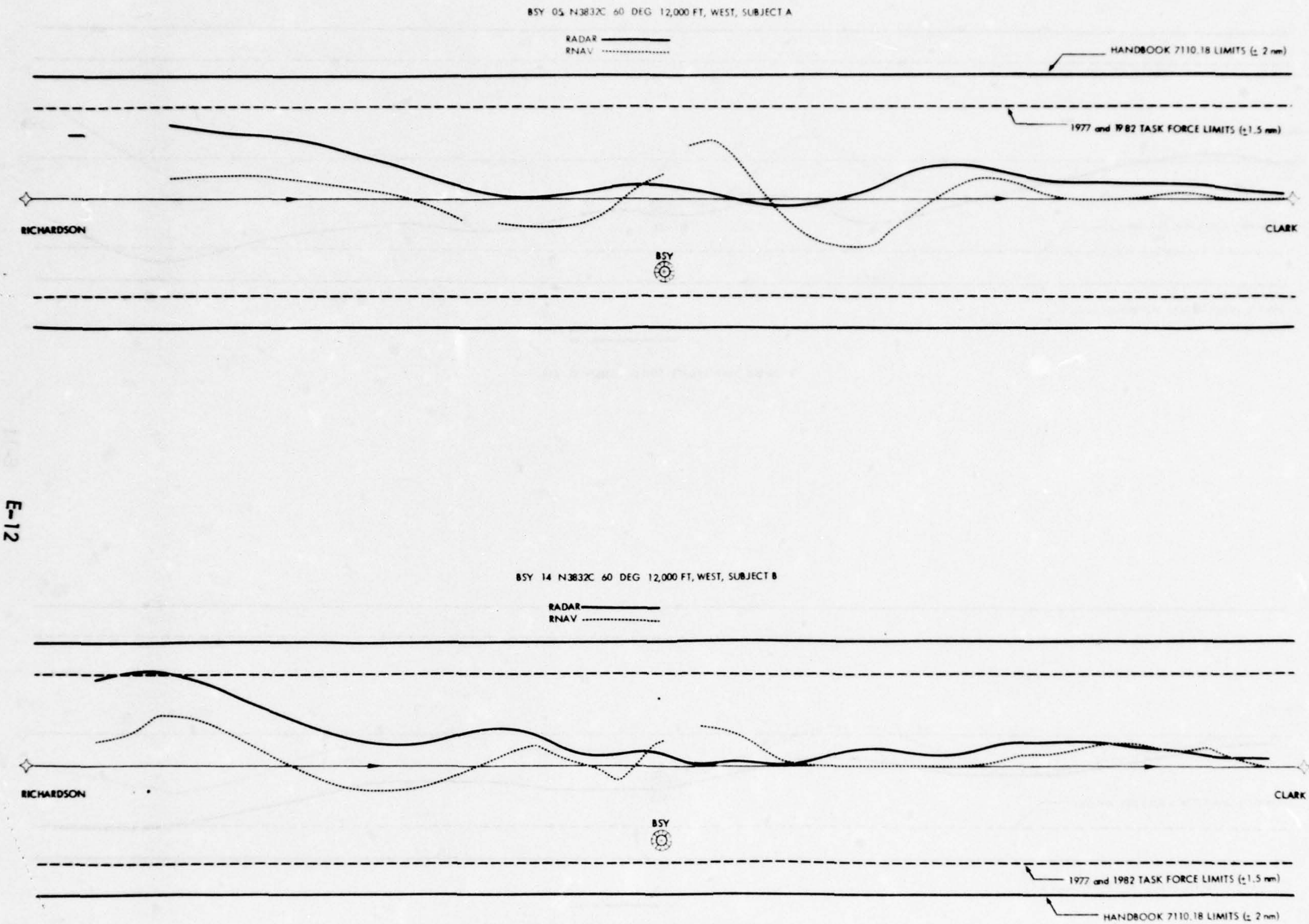


Figure E .9 SLANT RANGE ERROR FLIGHT TEST RESULTS

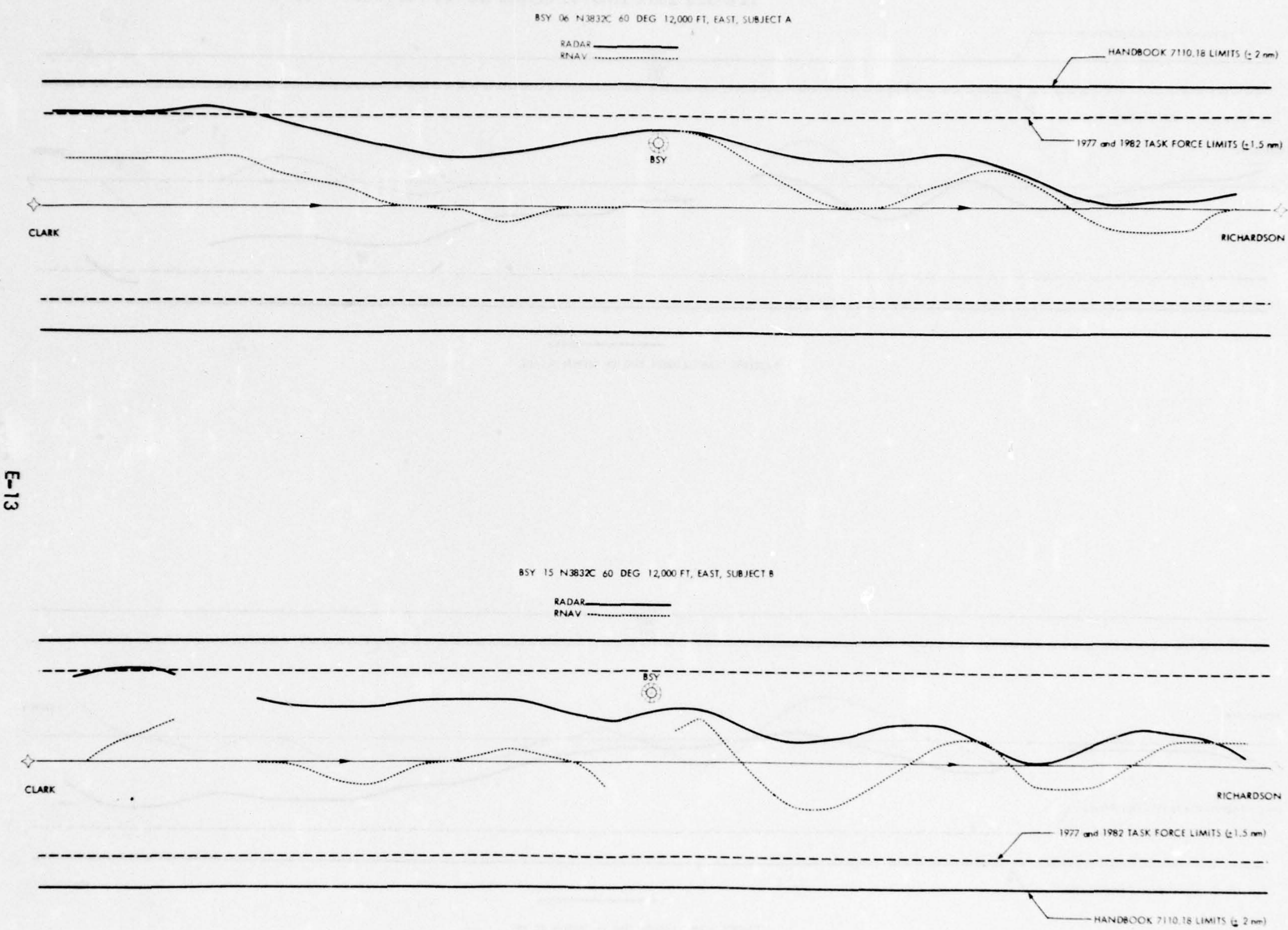


Figure E.10 SLANT RANGE ERROR FLIGHT TEST RESULTS

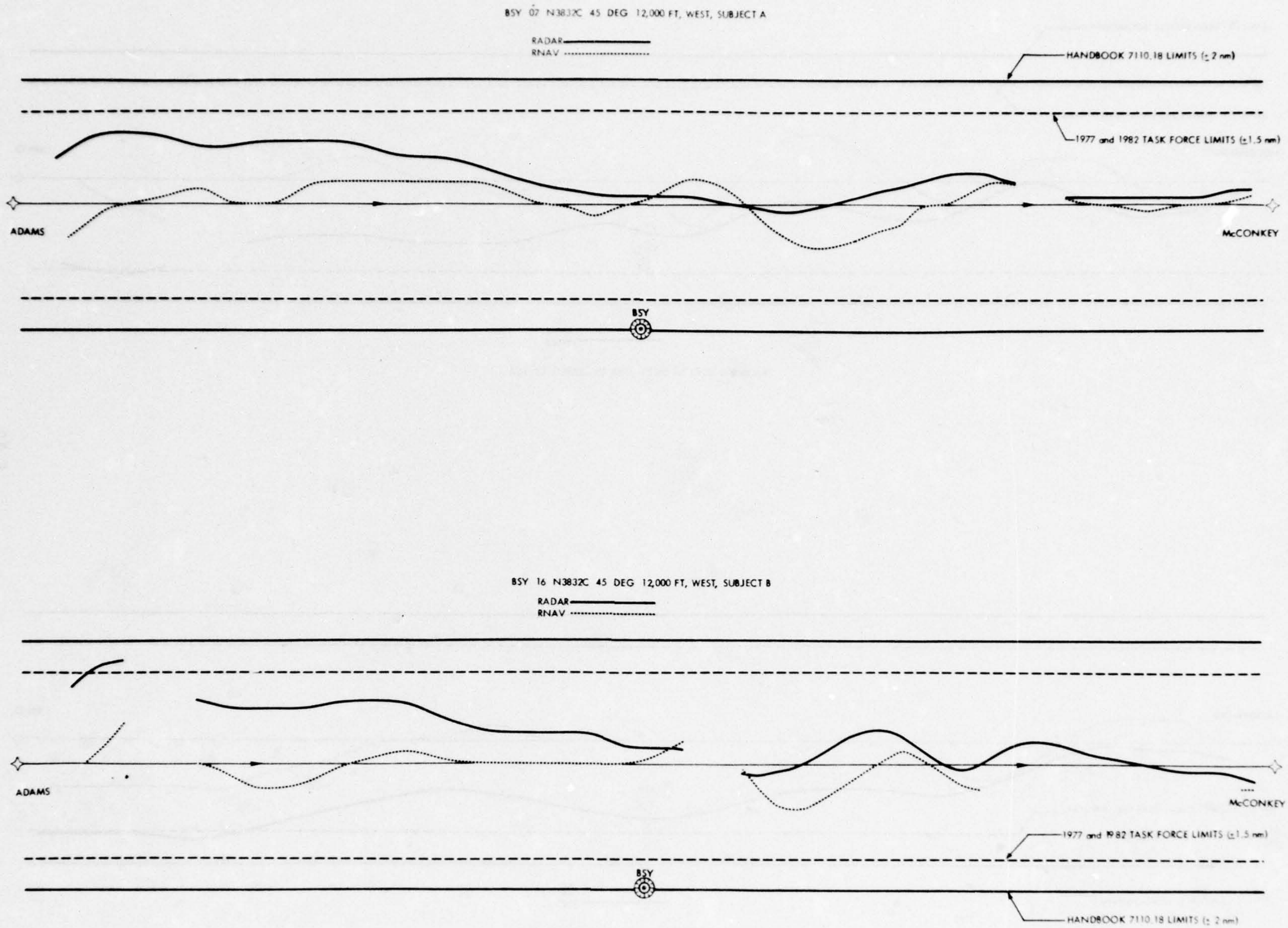


Figure E . 11 SLANT RANGE ERROR FLIGHT TEST RESULTS

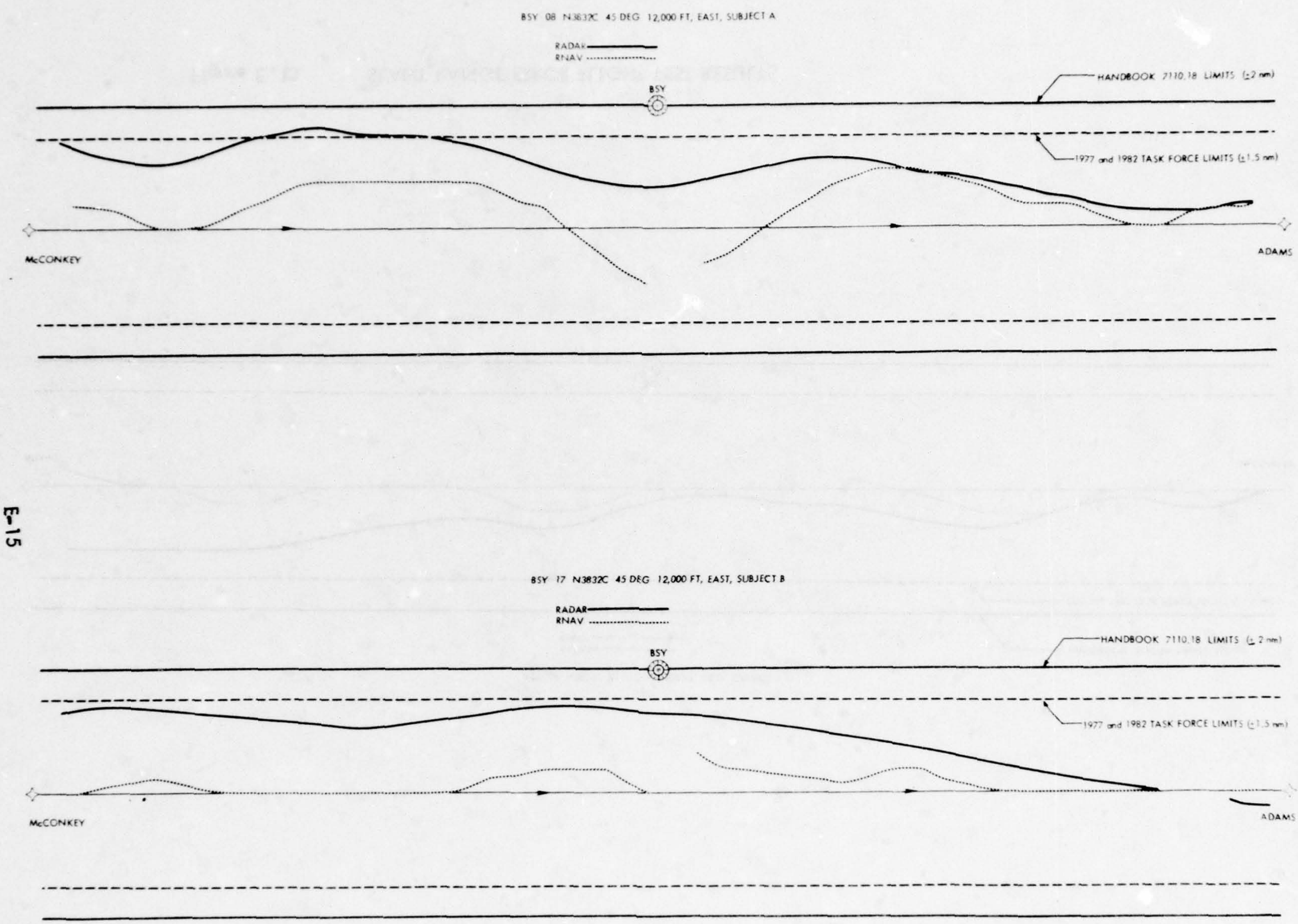


Figure E.12 SLANT RANGE ERROR FLIGHT TEST RESULTS

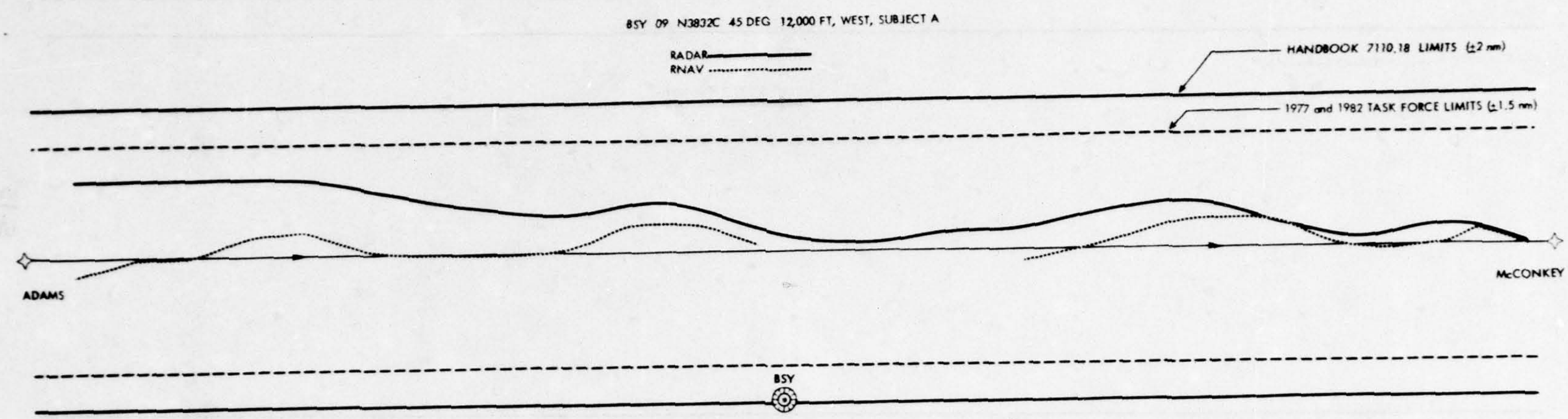


Figure E.13 SLANT RANGE ERROR FLIGHT TEST RESULTS

Appendix F

High Altitude VORTAC Requirements

Implementation Options and Cost Sensitivities

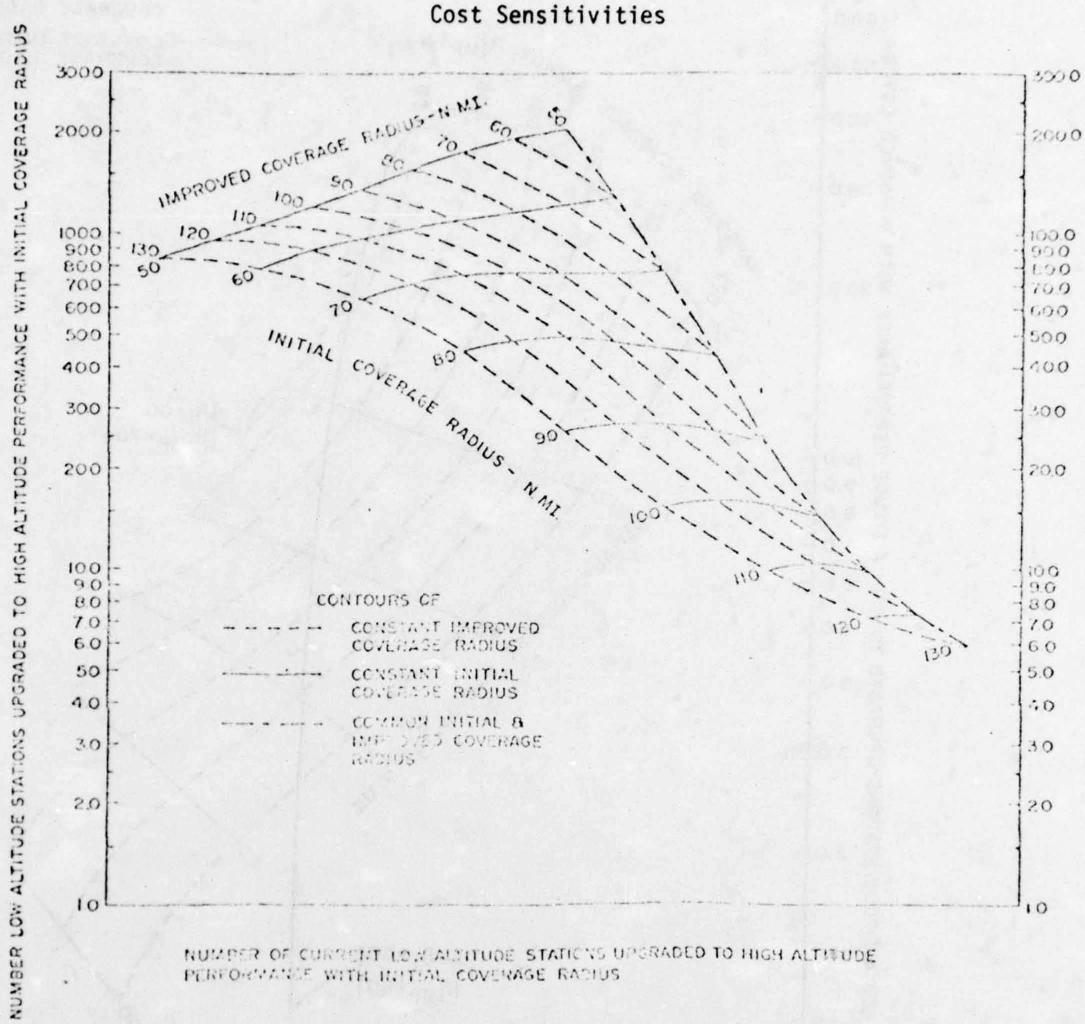


Figure F.1 Ground NAVAID System Implementation Cost To Provide Full CONUS Coverage

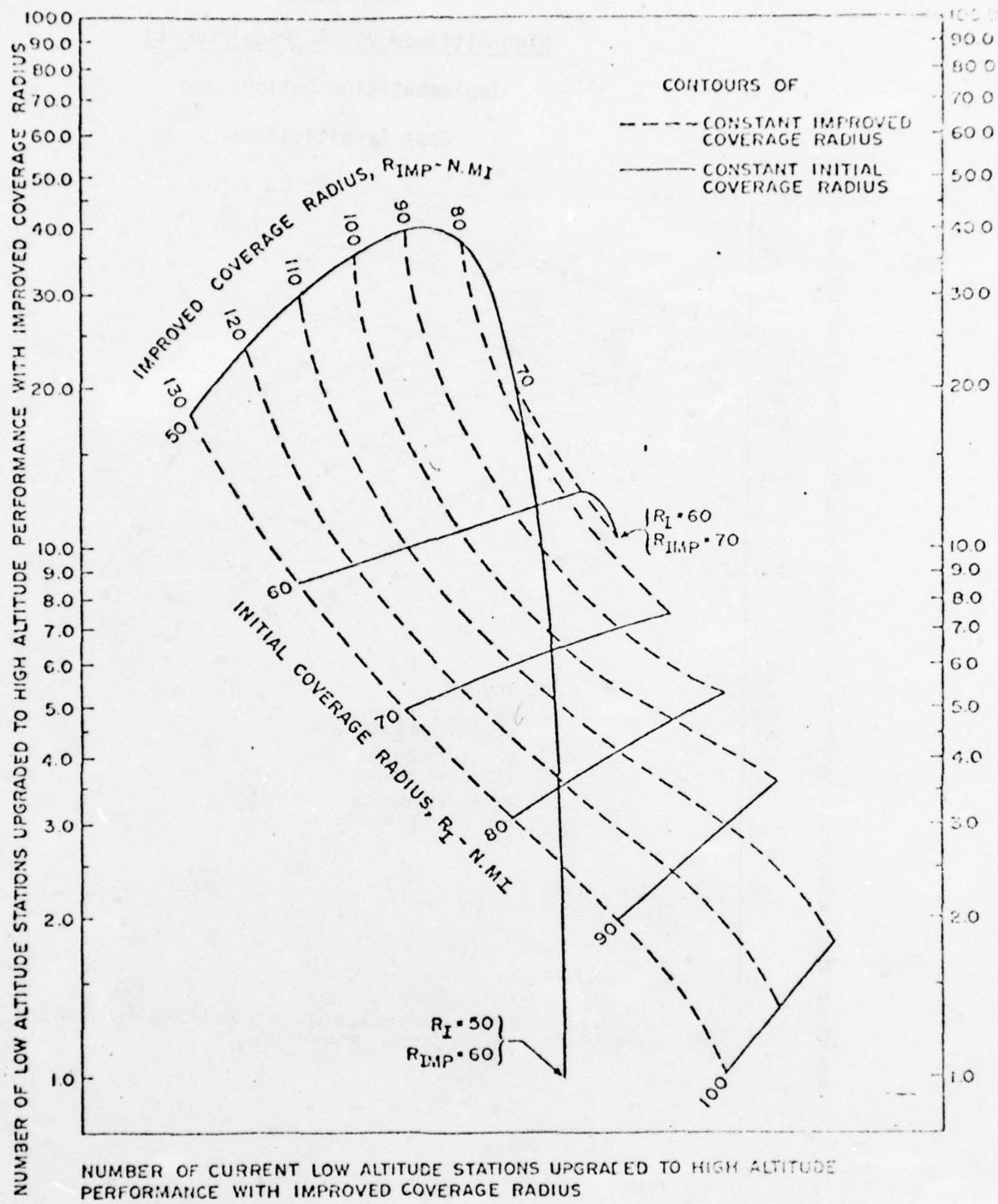


Figure F.2 Ground NAVAID System Implementation Costs To Provide Full CONUS Coverage

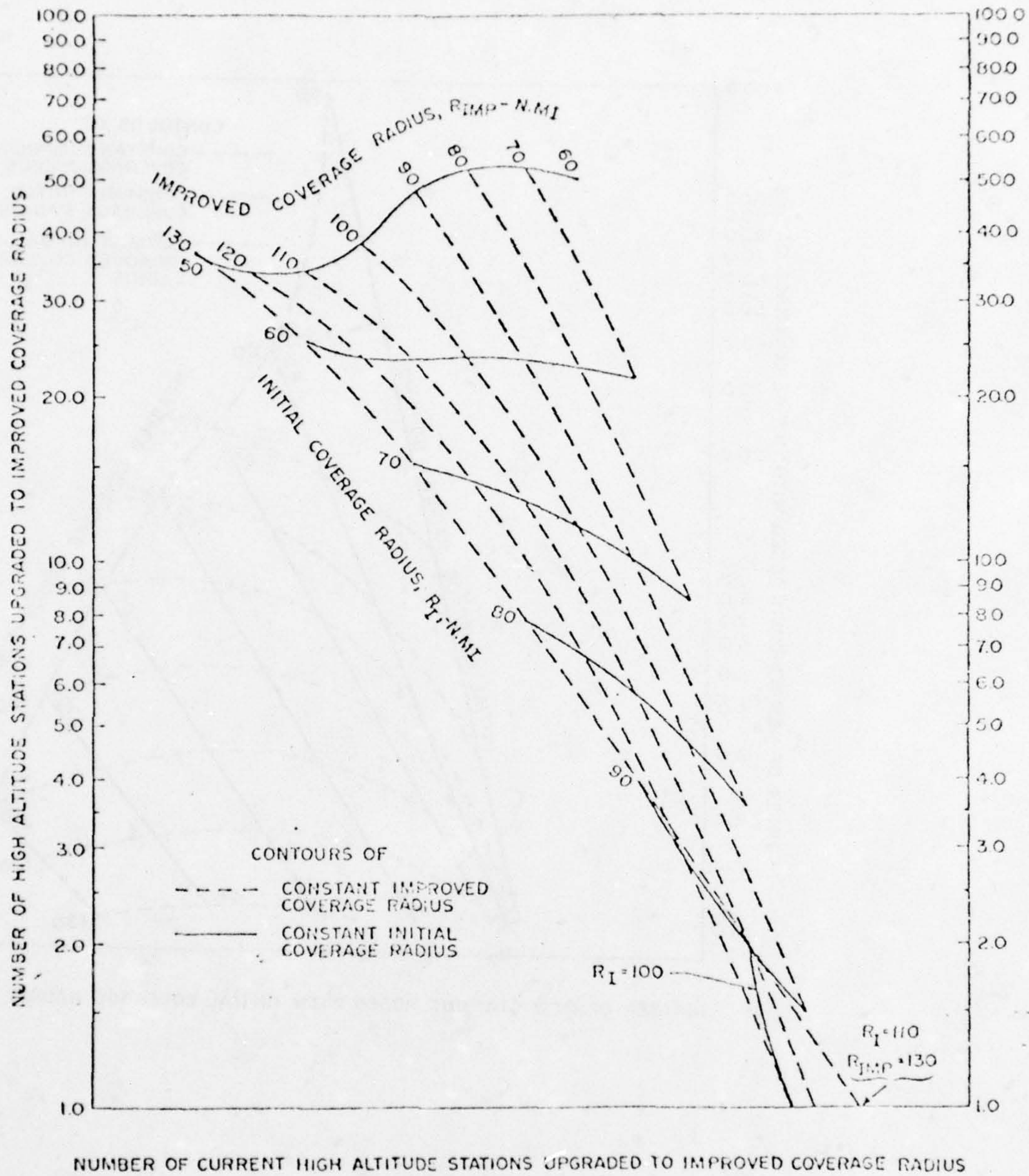


Figure F.3 Ground NAVAID System Implementation Costs To Provide Full CONUS Coverage

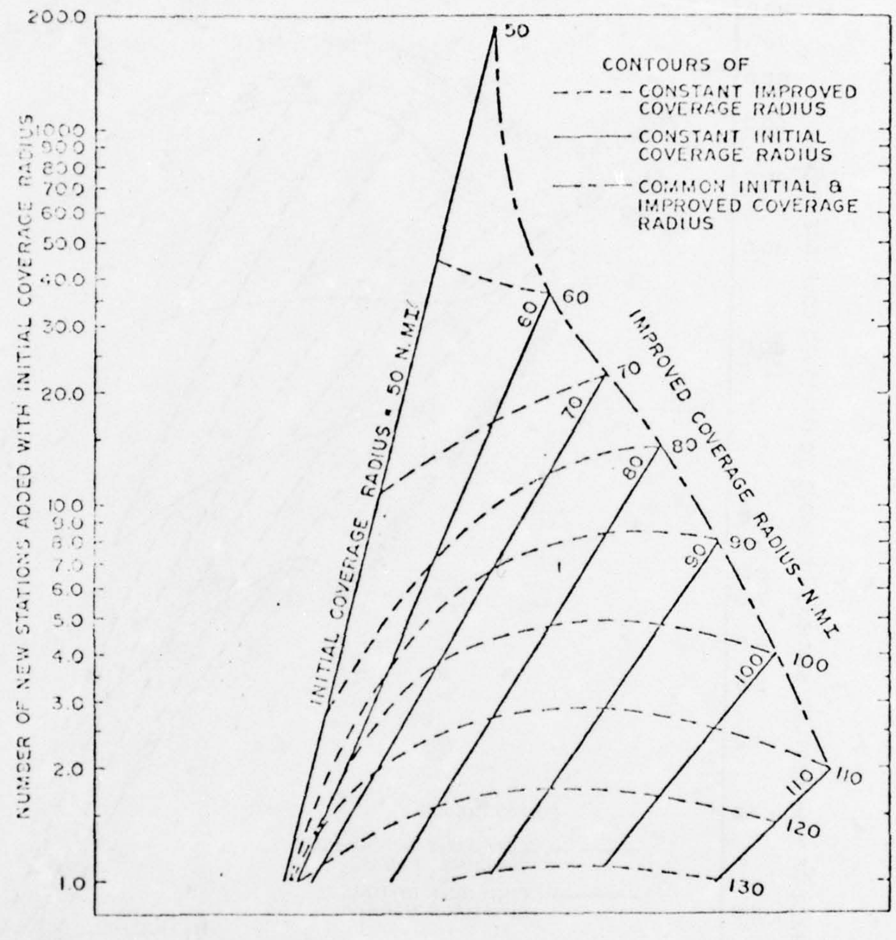


Figure F.4 Ground NAVAID System Implementation Costs To Provide Full CONUS Coverage

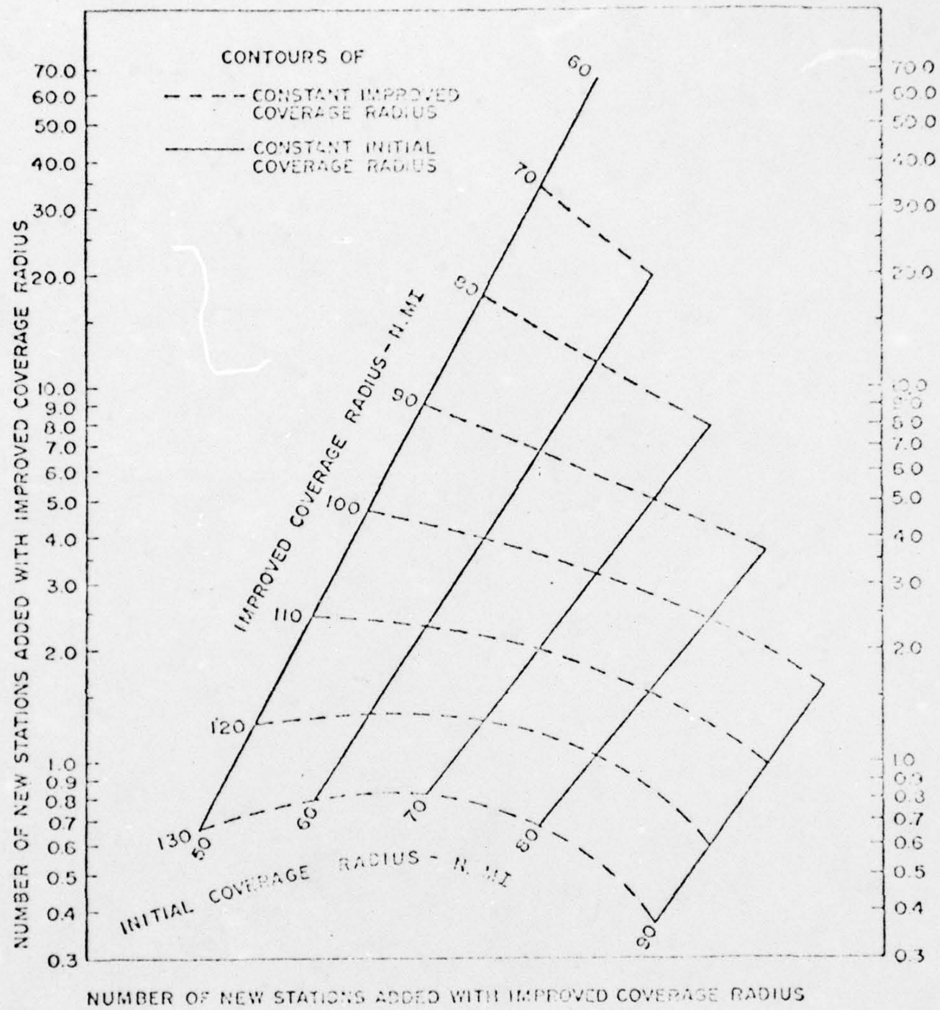


Figure F.5 Ground NAVAID System Implementation Cost To Provide Full CONUS Coverage

APPENDIX G

ENROUTE RNAV BENEFITS ANALYSIS (Six Airlines)

This appendix consists of listings of RNAV benefits available to each of six airlines, based on their 1 February 1976 schedule and operating frequency. Tables G.1 through G.6 give the time and fuel benefit for each airport pair in the current airline structure. Tables G.7 through G.12 list 2D and 3D annual and per aircraft benefits in fuel, time, and dollars for each aircraft type. Tables G.13 through G.18 list projected 4D benefits.

TABLE G.1
NATIONAL AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
BOS	JFK	415	76.0	17.00	72S	7	23880.	2.20	53.83
BOS	JFK	437	76.0	17.00	72S	7	23880.	2.20	53.83
CHS	DCA	420	294.0	3.00	727	7	35000.	.39	6.87
CHS	DCA	426	294.0	3.00	727	7	35000.	.39	6.87
DCA	CHS	421	289.0	-1.00	727	7	35000.	-.13	-2.29
DCA	CHS	423	289.0	-1.00	727	7	35000.	-.13	-2.29
DCA	JAX	443	465.0	7.00	72S	7	35000.	.92	17.50
DCA	JFK	73	100.0	-1.00	72S	7	25800.	-.13	-3.05
DCA	JFK	410	100.0	-1.00	727	7	25800.	-.13	-2.79
DCA	JFK	426	100.0	-1.00	727	7	25800.	-.13	-2.79
DCA	JFK	428	100.0	-1.00	727	7	25800.	-.13	-2.79
DCA	JFK	496	100.0	-1.00	727	7	25800.	-.13	-2.79
DCA	MIA	101	718.0	5.00	727	7	35000.	.65	11.45
DCA	MIA	109	718.0	5.00	727	7	35000.	.65	11.45
DCA	MIA	115	718.0	5.00	72S	7	35000.	.66	12.50
EWR	FLL	123	868.0	7.00	72S	7	35000.	.92	17.50
EWR	JAX	121	621.0	3.00	72S	7	35000.	.40	7.50
EWR	MIA	3	856.0	7.00	72S	7	35000.	.92	17.50
EWR	MIA	603	856.0	7.00	D10	7	41000.	.89	29.20
FLL	EWR	124	874.0	7.00	72S	7	35000.	.92	17.50
FLL	JFK	14	864.0	5.00	72S	7	35000.	.66	12.50
FLL	JFK	605	864.0	5.00	727	7	35000.	.65	11.45
JAX	DCA	422	462.0	7.00	727	7	35000.	.91	16.03
JAX	DCA	428	452.0	7.00	727	7	35000.	.91	16.03
JAX	EWR	70	626.0	4.00	72S	7	35000.	.53	10.00
JAX	MIA	175	203.0	0.00	727	7	32360.	0.00	0.00
JAX	MIA	407	203.0	0.00	727	7	32360.	0.00	0.00
JAX	MIA	411	203.0	0.00	72S	7	32360.	0.00	0.00
JFK	BOS	128	106.0	50.00	72S	7	26280.	6.37	150.04
JFK	BOS	188	106.0	50.00	72S	7	26280.	6.37	150.04
JFK	DCA	403	103.0	2.00	72S	7	26040.	.25	6.05
JFK	DCA	407	103.0	2.00	727	7	26040.	.25	5.54
JFK	DCA	421	103.0	2.00	727	7	26040.	.25	5.54
JFK	DCA	491	103.0	2.00	72S	7	26040.	.25	6.05
JFK	DCA	493	103.0	2.00	72S	7	26040.	.25	6.05
JFK	FLL	7	888.0	7.00	727	7	35000.	.91	16.03
JFK	FLL	607	888.0	7.00	72S	7	35000.	.92	17.50
JFK	JAX	439	626.0	5.00	727	7	35000.	.65	11.45
JFK	MIA	81	874.0	0.00	D10	7	41000.	0.00	0.00
JFK	MIA	97	874.0	0.00	72S	7	35000.	0.00	0.00
JFK	MIA	601	874.0	0.00	D10	7	41000.	0.00	0.00
JFK	TPA	67	789.0	6.00	727	7	35000.	.78	13.74
JFK	TPA	433	789.0	6.00	727	7	35000.	.78	13.74
JFK	TPA	437	789.0	6.00	72S	7	35000.	.79	15.00
LAS	LAX	21	104.0	2.00	D10	7	26120.	.25	11.26
LAS	SFO	25	293.0	0.00	72S	7	35000.	0.00	0.00
LAS	SFO	27	293.0	0.00	D10	7	36120.	0.00	0.00
LAX	LAS	10	103.0	3.00	D10	7	26040.	.37	16.91
LAX	MIA	42	1937.0	23.00	D10	7	41000.	2.91	95.95
LAX	MIA	50	1937.0	23.00	D10	7	41000.	2.91	95.95
LAX	MIA	54	1937.0	23.00	D10	7	41000.	2.91	95.95
LAX	MIA	68	1937.0	23.00	D10	7	41000.	2.91	95.95
LAX	MSY	34	1386.0	14.00	D10	7	41000.	1.77	58.40
LAX	TPA	36	-0.0	0.00	D10	7	12600.	0.00	0.00
LGA	MIA	55	865.0	7.00	72S	7	35000.	.92	17.50
LGA	MIA	91	865.0	7.00	727	7	35000.	.91	16.03
LGA	MIA	611	855.0	7.00	72S	7	35000.	.92	17.50
LGA	PBI	93	803.0	7.00	D10	7	41000.	.89	29.20
MIA	DCA	102	747.0	6.00	727	7	35000.	.78	13.74
MIA	DCA	106	747.0	6.00	727	7	35000.	.78	13.74
MIA	DCA	108	747.0	6.00	727	7	35000.	.78	13.74
MIA	EWR	8	889.0	7.00	D10	7	41000.	.89	29.20
MIA	EWR	126	889.0	7.00	72S	7	35000.	.92	17.50
MIA	EWR	602	889.0	7.00	72S	7	35000.	.92	17.50
MIA	JFK	4	881.0	8.00	72S	7	35000.	1.06	20.00
MIA	JFK	98	881.0	8.00	D10	7	41000.	1.01	33.37
MIA	JFK	600	881.0	8.00	D10	7	41000.	1.01	33.37
MIA	LAX	41	1937.0	13.00	D10	7	41000.	1.65	54.23
MIA	LAX	43	1937.0	13.00	D10	7	41000.	1.65	54.23
MIA	LAX	53	1937.0	13.00	D10	7	41000.	1.65	54.23
MIA	LGA	6	892.0	7.00	727	7	35000.	.91	16.03
MIA	LGA	90	892.0	7.00	72S	7	35000.	.92	17.50
MIA	LGA	608	892.0	7.00	72S	7	35000.	.92	17.50
MIA	MSY	25	509.0	2.00	72S	7	35000.	.26	5.00
MIA	MSY	27	509.0	2.00	D10	7	41000.	.25	8.34
MIA	MSY	45	509.0	2.00	D10	7	41000.	.25	8.34
MIA	SFO	35	2206.0	26.00	D10	7	41000.	3.29	108.46
MIA	SFO	49	2206.0	26.00	D10	7	41000.	3.29	108.46
MIA	TPA	21	90.0	-4.00	D10	7	25000.	-.50	-22.87
MIA	TPA	23	90.0	-4.00	D10	7	25000.	-.50	-22.87
MIA	TPA	475	90.0	-4.00	72S	7	25000.	-.51	-12.49
MSY	LAX	31	1354.0	13.00	D10	7	41000.	1.65	54.23
MSY	LAX	37	1354.0	13.00	D10	7	41000.	1.65	54.23
MSY	LAX	125	1354.0	13.00	D10	7	41000.	1.65	54.23
MSY	MIA	26	505.0	7.00	72S	7	35000.	.92	17.50
MSY	MIA	46	505.0	7.00	D10	7	41000.	.89	29.20
MSY	MIA	186	505.0	7.00	72S	7	35000.	.92	17.50
MSY	TPA	22	354.0	0.00	D10	7	38248.	0.00	0.00
MSY	TPA	34	354.0	0.00	D10	7	38248.	0.00	0.00
MSY	TPA	64	354.0	0.00	D10	7	38248.	0.00	0.00
MSY	TPA	182	354.0	0.00	72S	7	35000.	0.00	0.00
ORF	JFK	463	160.0	-5.00	727	7	30067.	-.64	-12.50
PBI	JFK	184	877.0	8.00	72S	7	35000.	1.06	20.00
PBI	JFK	188	877.0	8.00	72S	7	35000.	1.06	20.00
PBI	LGA	94	823.0	7.00	D10	7	41000.	.89	29.20
SFO	LAS	24	276.0	29.00	72S	7	35000.	3.83	72.51
SFO	LAS	44	276.0	29.00	D10	7	35520.	3.65	138.06
TPA	JFK	64	926.0	8.00	D10	7	41000.	1.01	33.37
TPA	JFK	436	924.0	8.00	727	7	35000.	1.04	18.32
TPA	MIA	10	103.0	18.00	D10	7	26040.	2.21	101.44
TPA	MIA	22	103.0	18.00	D10	7	26040.	2.21	101.44
TPA	MIA	32	103.0	18.00	72S	7	26040.	2.29	54.43
TPA	MIA	36	103.0	18.00	D10	7	26040.	2.21	101.44
TPA	MIA	44	103.0	18.00	D10	7	26040.	2.21	101.44
TPA	MIA	403	103.0	18.00	72S	7	26040.	2.29	54.43
TPA	MIA	439	103.0	18.00	727	7	26040.	2.27	49.84
TPA	MSY	23	353.0	0.00	D10	7	38216.	0.00	0.00
TPA	MSY	37	353.0	0.00	D10	7	38216.	0.00	0.00
TPA	MSY	125	353.0	0.00	D10	7	38216.	0.00	0.00

TABLE G.2
EASTERN AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
ATL	BAL	126	388.0	14.00	D9S	7	34480.	1.89	23.45
ATL	BAL	132	388.0	14.00	D9S	7	34480.	1.89	23.45
ATL	BAL	134	388.0	14.00	D9S	7	34480.	1.89	23.45
ATL	BAL	136	388.0	14.00	D9S	1	34480.	1.89	23.45
ATL	BAL	138	388.0	14.00	D9S	7	34480.	1.89	23.45
ATL	BAL	424	388.0	14.00	727	1	35000.	1.83	32.05
ATL	BAL	434	388.0	14.00	72S	6	35000.	1.85	35.00
ATL	BNA	284	98.0	1.00	D9S	7	27640.	.13	1.95
ATL	BNA	620	98.0	1.00	72S	7	25640.	.13	3.06
ATL	BNA	624	98.0	1.00	72S	7	25640.	.13	3.06
ATL	BNA	670	98.0	1.00	72S	7	25640.	.13	3.06
ATL	BNA	676	98.0	1.00	D9S	7	27640.	.13	1.95
ATL	BOS	116	770.0	6.00	727	7	35000.	.78	13.74
ATL	BOS	128	770.0	6.00	L10	7	41000.	.74	26.78
ATL	BOS	144	770.0	6.00	727	6	35000.	.78	13.74
ATL	BOS	534	770.0	6.00	727	7	35000.	.78	13.74
ATL	BUF	330	535.0	4.00	727	7	35000.	.52	9.16
ATL	BUF	632	535.0	4.00	72S	7	35000.	.53	10.00
ATL	BUF	962	535.0	4.00	L10	7	41000.	.49	17.85
ATL	CLT	322	116.0	8.00	727	7	27080.	1.01	21.43
ATL	CLT	324	116.0	8.00	D9S	7	29040.	1.05	15.01
ATL	CLT	348	116.0	8.00	D9S	7	29040.	1.05	15.01
ATL	CLT	360	116.0	8.00	72S	7	27080.	1.02	23.41
ATL	CLT	476	116.0	8.00	72S	7	27080.	1.02	23.41
ATL	CLT	652	116.0	8.00	72S	7	27080.	1.02	23.41
ATL	DCA	130	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DCA	146	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DCA	380	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DCA	904	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DF*	135	555.0	1.00	DC9	7	35000.	.13	1.57
ATL	DF*	451	555.0	1.00	DC9	7	35000.	.13	1.57
ATL	DF*	523	555.0	1.00	727	7	35000.	.13	2.29
ATL	DF*	573	555.0	1.00	D9S	7	35000.	.14	1.66
ATL	DF*	577	555.0	1.00	727	7	35000.	.13	2.29
ATL	EWR	106	585.0	4.00	727	7	35000.	.52	9.16
ATL	EWR	110	585.0	4.00	727	7	35000.	.52	9.16
ATL	EWR	112	585.0	4.00	72S	6	35000.	.53	10.00
ATL	EWR	112	585.0	4.00	72S	1	35000.	.53	10.00
ATL	EWR	811	585.0	4.00	L10	7	41000.	.49	17.85
ATL	GSO	362	178.0	0.00	D9S	7	31347.	0.00	0.00
ATL	GSO	368	178.0	0.00	72S	7	31027.	0.00	0.00
ATL	GSO	580	178.0	0.00	D9S	7	31347.	0.00	0.00
ATL	GSO	682	178.0	0.00	72S	7	31027.	0.00	0.00
ATL	JAX	86	146.0	-6.00	727	7	29320.	-.76	-15.16
ATL	JAX	281	146.0	-6.00	72S	7	29320.	-.77	-16.56
ATL	JAX	397	146.0	-6.00	727	7	29320.	-.76	-15.16
ATL	JAX	533	146.0	-6.00	D9S	7	30240.	-.79	-10.94
ATL	JAX	578	146.0	-6.00	D9S	7	30240.	-.79	-10.94
ATL	JAX	677	146.0	-6.00	72S	7	29320.	-.77	-16.56
ATL	JFK	108	691.0	4.00	727	7	35000.	.52	9.16
ATL	JFK	444	691.0	4.00	DC9	7	35000.	.53	6.27
ATL	LAX	83	1642.0	17.00	727	7	35000.	2.22	38.92
ATL	LAX	87	1642.0	17.00	727	6	35000.	2.22	38.92
ATL	LAX	87	1642.0	17.00	727	1	35000.	2.22	38.92
ATL	LAX	89	1642.0	17.00	727	7	35000.	2.22	38.92
ATL	LGA	80	567.0	4.00	727	7	35000.	.52	9.16
ATL	LGA	100	567.0	4.00	D9S	7	35000.	.54	6.64
ATL	LGA	102	567.0	4.00	727	7	35000.	.52	9.16
ATL	LGA	432	567.0	4.00	D9S	7	35000.	.54	6.64
ATL	LGA	544	567.0	4.00	727	7	35000.	.52	9.16
ATL	LGA	572	567.0	4.00	72S	7	35000.	.53	10.00
ATL	MEM	660	217.0	12.00	DC9	7	32387.	1.57	19.72
ATL	MEM	662	217.0	12.00	D9S	7	32397.	1.60	20.89
ATL	MEM	980	217.0	12.00	727	7	33080.	1.55	28.70
ATL	MEM	982	217.0	12.00	72S	7	33080.	1.57	31.34
ATL	MIA	97	470.0	41.00	727	7	35000.	5.35	93.87
ATL	MIA	219	470.0	41.00	727	7	35000.	5.35	93.87
ATL	MIA	265	470.0	41.00	D9S	7	35000.	5.54	68.05
ATL	MIA	387	470.0	41.00	D9S	7	35000.	5.54	68.05
ATL	MIA	393	470.0	41.00	727	7	35000.	5.35	93.87
ATL	MIA	649	470.0	41.00	D9S	7	35000.	5.54	68.05
ATL	MSY	147	288.0	4.00	D9S	7	33480.	.54	6.82
ATL	MSY	149	288.0	4.00	727	7	35000.	.52	9.16
ATL	MSY	287	288.0	4.00	72S	7	35000.	.53	10.00
ATL	MSY	429	288.0	4.00	727	7	35000.	.52	9.16
ATL	MSY	793	288.0	4.00	DC9	7	33480.	.52	6.44
ATL	ORD	240	424.0	-2.00	DC9	7	34840.	-.26	-3.14
ATL	ORD	242	424.0	-2.00	72S	7	35000.	-.26	-5.00
ATL	ORD	244	424.0	-2.00	72S	5	35000.	-.26	-5.00
ATL	ORD	244	424.0	-2.00	727	2	35000.	-.26	-4.58
ATL	ORD	246	424.0	-2.00	DC9	7	34840.	-.26	-3.14
ATL	ORD	248	424.0	-2.00	DC9	7	34840.	-.26	-3.14
ATL	ORD	954	424.0	-2.00	L10	7	40480.	-.25	-9.07
ATL	PBI	141	389.0	-39.00	72S	7	35000.	-5.15	-97.51
ATL	PBI	245	389.0	-39.00	727	7	35000.	-5.09	-89.29
ATL	PBI	269	389.0	-39.00	DC9	7	34490.	-5.14	-61.66
ATL	PBI	329	389.0	-39.00	72S	7	35000.	-5.15	-97.51
ATL	PHL	114	506.0	13.00	D9S	7	35000.	1.76	21.58
ATL	PHL	120	506.0	13.00	727	7	35000.	1.70	29.76
ATL	PHL	122	506.0	13.00	D9S	7	35000.	1.76	21.58
ATL	PHL	124	506.0	13.00	D9S	7	35000.	1.76	21.58
ATL	PHL	140	506.0	13.00	L10	7	41000.	1.61	58.03
ATL	PHL	486	506.0	13.00	72S	7	35000.	1.72	32.50
ATL	PIT	320	376.0	5.00	727	7	35000.	.65	11.45
ATL	PIT	336	376.0	5.00	727	7	35000.	.65	11.45
ATL	PIT	988	376.0	5.00	72S	7	35000.	.66	12.50
ATL	SDF	252	190.0	-3.00	D9S	7	31667.	-.40	-5.30
ATL	SDF	254	190.0	-3.00	D9S	7	31667.	-.40	-5.30
ATL	SDF	256	190.0	-3.00	DC9	7	31667.	-.39	-5.00
ATL	SDF	462	190.0	-3.00	D9S	7	31667.	-.40	-5.30
ATL	SDF	712	190.0	-3.00	D9S	7	31667.	-.40	-5.30
ATL	STL	98	360.0	29.00	L10	7	38440.	3.59	139.76
ATL	STL	270	360.0	29.00	72S	7	35000.	3.83	72.51
ATL	STL	272	360.0	29.00	D9S	7	34200.	3.90	48.82
ATL	STL	274	360.0	29.00	D9S	7	34200.	3.90	48.82
ATL	STL	276	360.0	29.00	D9S	7	34200.	3.90	48.82
ATL	STL	452	360.0	29.00	727	7	35000.	3.78	66.40
ATL	TPA	289	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	299	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	365	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	485	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	629	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	727	277.0	11.00	72S	7	35000.	1.45	27.50
BAL	ATL	131	387.0	9.00	D9S	7	34470.	1.21	15.08
BAL	ATL	147	387.0	9.00	D9S	7	34470.	1.21	15.08
BAL	ATL	633	387.0	9.00	D9S	1	34470.	1.21	15.08
BAL	ATL	667	387.0	9.00	D9S	7	34470.	1.21	15.08
BAL	BOS	424	261.0	17.00	727	1	34840.	2.22	39.07
BAL	BOS	434	261.0	17.00	72S	6	34840.	2.24	42.66
BDL	DCA	593	187.0	23.00	D9S	7	31587.	3.06	40.69
BDL	DCA	689	187.0	23.00	D9S	7	31587.	3.06	40.69
BDL	MIA	181	-0.0	0.00	72S	7	12600.	0.00	0.00
BHM	ORD	224	434.0	30.00	D9S	7	34940.	4.05	49.84
BNA	ATL	299	100.0	4.00	72S	7	25800.	.51	12.19
BNA	ATL	399	100.0	4.00	D9S	7	27800.	.52	7.75
BNA	ATL	629	100.0	4.00	72S	7	25800.	.51	12.19
BNA	ATL	671	100.0	4.00	D9S	7	27800.	.52	7.75
BNA	ATL	695	100.0	4.00	72S	7	25800.	.51	12.19
BNA	ORD	258	258.0	6.00	727	7	34720.	.78	13.83
BNA	ORD	894	258.0	6.00	DC9	7	33180.	.79	9.71
BOS	ATL	129	748.0	5.00	72S	7	35000.	.66	12.50
BOS	ATL	145	748.0	5.00	727	7	35000.	.65	11.45
BOS	ATL	149	748.0	5.00	727	7	35000.	.65	11.45
BOS	ATL	533	748.0	5.00	D9S	7	35000.	.68	8.30
BOS	ATL	537	748.0	5.00	72S	6	35000.	.66	12.50
BOS	ATL	537	748.0	5.00	72S	1	35000.	.66	12.50
BOS	DCA	199	244.0	0.00	727	7	34160.	0.00	0.00
BOS	DCA	377	244.0	0.00	D9S	7	33040.	0.00	0.00
BOS	DCA	393	244.0	0.00	727	7	34160.	0.00	0.00
BOS	DCA	509	244.0	0.00	72S	7	34160.	0.00	0.00
BOS	DCA	869	244.0	0.00	D9S	7	33040.	0.00	0.00
BOS	JFK	491	76.0	17.00	72S	6	23880.	2.20	53.83
BOS	JFK	887	76.0	17.00	727	7	23880.	2.17	49.30
BOS	MIA	41	1030.0	0.00	72S	7	35000.	0.00	0.00
BOS	MIA	43	1030.0	0.00	727	7	35000.	0.00	0.00
BOS	MIA	47	1030.0	0.00	727	7	35000.	0.00	0.00
BOS	MIA	419	1030.0	0.00	727	7	35000.	0.00	0.00
BOS	PHL	809	195.0	35.00	L10	7	31933.	4.25	186.14
BUF	ATL	345	551.0	4.00	727	7	35000.	.52	9.16
BUF	ATL	625	551.0	4.00	72S	7	35000.	.53	10.00
BUF	ATL	961	551.0	4.00	L10	7	41000.	.49	17.85
BUF	PHL	125	191.0	38.00	727	7	31720.	4.89	92.77
CLT	JFK	356	390.0	25.00	D9S	7	34500.	3.37	41.87
CLT	ORD	212	428.0	10.00	D9S	7	34880.	1.35	16.63
CLT	ORD	214	428.0	10.00	D9S	7	34880.	1.35	16.63
CLT	ORD	218	428.0	10.00	D9S	7	34880.	1.35	16.63
CLT	ORD	226	428.0	10.00	D9S	7	34880.	1.35	16.63
CLT	PHL	374	312.0	12.00	D9S	7	33720.	1.61	20.37
CLT	PHL	590	312.0	12.00	727	7	35000.	1.57	27.47
CLT	PHL	596	312.0	12.00	727	7	35000.	1.57	27.47
CLT	PHL	608	312.0	12.00	72S	7	35000.	1.58	30.00
CLT	PIT	310	240.0	10.00	D9S	7	33000.	1.34	17.19
CLT	PIT	334	240.0	10.00	D9S	7	33000.	1.34	17.19

TABLE G.2
EASTERN AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
CLT	PIT	348	240.0	10.00	D9S	7	33000.	1.34	17.19
CLT	PIT	476	240.0	10.00	72S	7	34000.	1.31	25.58
DCA	BOS	372	261.0	17.00	727	7	34840.	2.22	39.07
DCA	BOS	398	261.0	17.00	727	7	34840.	2.22	39.07
DCA	BOS	566	261.0	17.00	D9S	7	33210.	2.28	29.12
DCA	BOS	866	261.0	17.00	D9S	7	33210.	2.28	29.12
DCA	BOS	878	261.0	17.00	D9S	7	33210.	2.28	29.12
DCA	CLT	375	206.0	12.00	D9S	7	32093.	1.60	21.01
DCA	CLT	385	206.0	12.00	D9S	7	32093.	1.60	21.01
DCA	CLT	391	206.0	12.00	727	7	32520.	1.55	28.95
DCA	CLT	657	206.0	12.00	72S	7	32520.	1.57	31.62
DCA	JAX	199	465.0	7.00	727	7	35000.	.91	16.03
DCA	JAX	869	465.0	7.00	D9S	7	35000.	.95	11.62
DCA	LGA	1400	66.0	-3.00	D9S	5	26040.	-.39	-6.10
DCA	LGA	1410	66.0	-3.00	D9S	6	26040.	-.39	-6.10
DCA	LGA	1420	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1430	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1440	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1450	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1460	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1470	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1480	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1490	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1500	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1510	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1520	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	LGA	1530	66.0	-3.00	D9S	6	26040.	-.39	-6.10
DCA	LGA	1540	66.0	-3.00	D9S	7	26040.	-.39	-6.10
DCA	MIA	175	718.0	5.00	D9S	7	35000.	.68	8.30
DCA	MIA	177	718.0	5.00	D9S	7	35000.	.68	8.30
DCA	MIA	195	718.0	5.00	727	7	35000.	.65	11.45
DCA	MIA	197	718.0	5.00	D9S	7	35000.	.68	8.30
DCA	MIA	473	718.0	5.00	D9S	7	35000.	.68	8.30
DCA	SDF	370	320.0	7.00	D9S	7	33800.	.94	11.87
DCA	SDF	509	320.0	7.00	72S	7	35000.	.92	17.50
DCA	STL	503	544.0	4.00	D9S	7	35000.	.54	6.64
DFW	ATL	114	563.0	4.00	D9S	7	35000.	.54	6.64
DFW	ATL	120	563.0	4.00	727	7	35000.	.52	9.16
DFW	ATL	286	563.0	4.00	DC9	7	35000.	.53	6.27
DFW	ATL	586	563.0	4.00	D9S	7	35000.	.54	6.64
DFW	ATL	666	563.0	4.00	727	7	35000.	.52	9.16
DTW	ORD	804	101.0	-4.00	727	1	25880.	-.50	-11.13
DTW	PIT	341	85.0	-1.00	727	7	24600.	-.13	-2.87
DTW	PIT	349	85.0	-1.00	D9S	7	26800.	-.13	-1.99
DTW	PIT	739	85.0	-1.00	727	7	24600.	-.13	-2.87
DTW	TPA	335	-0.0	0.00	D9S	7	18200.	0.00	0.00
DTW	TPA	463	-0.0	0.00	D9S	7	18200.	0.00	0.00
DTW	TPA	639	-0.0	0.00	D9S	7	18200.	0.00	0.00
EWR	ATL	105	569.0	4.00	72S	7	35000.	.53	10.00
EWR	ATL	135	569.0	4.00	DC9	7	35000.	.53	6.27
EWR	ATL	806	569.0	4.00	L10	7	41000.	.49	17.85
EWR	CLT	353	377.0	6.00	727	7	35000.	.78	13.74
EWR	CLT	359	377.0	6.00	D9S	7	34370.	.81	10.07
EWR	CLT	383	377.0	6.00	D9S	7	34370.	.81	10.07
EWR	FLL	407	868.0	7.00	72S	7	35000.	.92	17.50
EWR	FLL	745	868.0	7.00	727	7	35000.	.91	16.03
EWR	FLL	749	868.0	7.00	D9S	7	35000.	.95	11.62
EWR	FLL	759	868.0	7.00	727	7	35000.	.91	16.03
EWR	IAD	559	60.0	0.00	727	7	22200.	0.00	0.00
EWR	MIA	3	856.0	7.00	72S	7	35000.	.92	17.50
EWR	MIA	5	856.0	7.00	727	5	35000.	.91	16.03
EWR	MIA	5	856.0	7.00	D9S	2	35000.	.95	11.62
EWR	MIA	7	856.0	7.00	72S	7	35000.	.92	17.50
EWR	MIA	403	856.0	7.00	727	7	35000.	.91	16.03
EWR	TPA	165	811.0	7.00	L10	7	41000.	.87	31.25
EWR	TPA	423	811.0	7.00	D9S	7	35000.	.95	11.62
FLL	BOS	864	1029.0	9.00	727	7	35000.	1.17	20.61
FLL	BOS	880	1029.0	9.00	727	7	35000.	1.17	20.61
FLL	EWR	405	874.0	7.00	727	7	35000.	.91	16.03
FLL	EWR	742	874.0	7.00	72S	7	35000.	.92	17.50
FLL	EWR	746	874.0	7.00	D9S	7	35000.	.95	11.62
FLL	EWR	758	874.0	7.00	727	7	35000.	.91	16.03
FLL	JFK	412	864.0	5.00	L10	7	41000.	.62	22.32
FLL	JFK	750	864.0	5.00	727	7	35000.	.65	11.45
FLL	JFK	756	864.0	5.00	D9S	7	35000.	.68	8.30
FLL	ORD	468	957.0	8.00	727	7	35000.	1.04	18.32
FLL	ORD	790	957.0	8.00	727	7	35000.	1.04	18.32
FLL	ORD	796	957.0	8.00	727	7	35000.	1.04	18.32
FLL	PHL	408	853.0	7.00	727	7	35000.	.91	16.03
FLL	PHL	876	853.0	7.00	727	7	35000.	.91	16.03

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
FLL	TPA	180	90.0	-4.00	D9S	7	27000.	-.52	-7.92
FLL	TPA	342	90.0	-4.00	D9S	7	27000.	-.52	-7.92
FLL	TPA	500	90.0	-4.00	D9S	7	27000.	-.52	-7.92
GSO	LGA	362	304.0	11.00	D9S	7	33640.	1.48	18.70
GSO	LGA	366	304.0	11.00	D9S	7	33640.	1.48	18.70
GSO	LGA	580	304.0	11.00	D9S	7	33640.	1.48	18.70
GSO	ORD	206	434.0	0.00	DC9	7	34940.	0.00	0.00
GSO	ORD	363	434.0	0.00	D9S	7	34940.	0.00	0.00
IAD	EWR	558	99.0	-3.00	727	7	25720.	-.38	-8.39
IAD	JFK	554	100.0	-1.00	72S	7	25800.	-.13	-3.05
IAD	MSY	553	761.0	16.00	727	7	35000.	2.09	36.63
JAX	ATL	364	148.0	2.00	72S	7	29427.	.26	5.51
JAX	ATL	368	148.0	2.00	72S	7	29427.	.26	5.51
JAX	ATL	478	148.0	2.00	72S	7	29427.	.26	5.51
JAX	ATL	630	148.0	2.00	72S	5	29427.	.26	5.51
JAX	ATL	630	148.0	2.00	727	2	29427.	.25	5.05
JAX	ATL	676	148.0	2.00	D9S	7	30320.	.26	3.64
JAX	ATL	682	148.0	2.00	72S	7	29427.	.26	5.51
JAX	DCA	866	462.0	7.00	D9S	7	35000.	.95	11.62
JAX	DCA	878	462.0	7.00	D9S	7	35000.	.95	11.62
JAX	JFK	156	634.0	5.00	D9S	7	35000.	.68	8.30
JAX	MIA	397	203.0	0.00	727	7	32360.	0.00	0.00
JFK	ATL	103	572.0	18.00	72S	7	35000.	2.38	45.00
JFK	ATL	111	572.0	18.00	D9S	7	35000.	2.43	29.87
JFK	ATL	445	572.0	18.00	D9S	7	35000.	2.43	29.87
JFK	ATL	491	572.0	18.00	72S	6	35000.	2.38	45.00
JFK	BOS	494	106.0	50.00	727	7	26280.	6.30	137.40
JFK	FLL	477	888.0	7.00	L10	7	41000.	.87	31.25
JFK	FLL	743	888.0	7.00	72S	7	35000.	.92	17.50
JFK	FLL	755	888.0	7.00	D9S	7	35000.	.95	11.62
JFK	IAD	555	104.0	3.00	727	7	26120.	.38	8.29
JFK	MIA	9	874.0	0.00	L10	7	41000.	0.00	0.00
JFK	MIA	15	874.0	0.00	727	7	35000.	0.00	0.00
JFK	MIA	23	874.0	0.00	727	7	35000.	0.00	0.00
JFK	MIA	27	874.0	0.00	L10	7	41000.	0.00	0.00
JFK	MIA	401	874.0	0.00	L10	7	41000.	0.00	0.00
JFK	MIA	405	874.0	0.00	727	7	35000.	0.00	0.00
JFK	MSY	65	952.0	8.00	727	7	35000.	1.04	18.32
JFK	MSY	69	952.0	8.00	727	7	35000.	1.04	18.32
JFK	TPA	161	789.0	6.00	DC9	7	35000.	.79	9.40
JFK	TPA	167	789.0	6.00	727	7	35000.	.78	13.74
JFK	TPA	425	789.0	6.00	D9S	7	35000.	.81	9.96
LGA	ATL	87	560.0	4.00	727	6	35000.	.52	9.16
LGA	ATL	87	560.0	4.00	727	1	35000.	.52	9.16
LGA	ATL	101	560.0	4.00	727	7	35000.	.52	9.16
LGA	ATL	115	560.0	4.00	D9S	7	35000.	.54	6.64
LGA	ATL	543	560.0	4.00	72S	7	35000.	.53	10.00
LGA	ATL	547	560.0	4.00	D9S	7	35000.	.54	6.64
LGA	BHM	541	654.0	5.00	D9S	7	35000.	.68	8.30
LGA	CLT	351	387.0	16.00	727	7	35000.	2.09	36.63
LGA	CLT	357	387.0	16.00	72S	6	35000.	2.11	40.00
LGA	CLT	357	387.0	16.00	72S	1	35000.	2.11	40.00
LGA	CLT	397	387.0	16.00	727	7	35000.	2.09	36.63
LGA	CLT	545	387.0	16.00	D9S	7	34470.	2.16	26.81
LGA	DCA	1401	105.0	4.00	D9S	5	28200.	.52	7.67
LGA	DCA	1411	105.0	4.00	D9S	6	28200.	.52	7.67
LGA	DCA	1421	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1431	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1441	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1451	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1461	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1481	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1491	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1501	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1511	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1521	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	DCA	1531	105.0	4.00	D9S	6	28200.	.52	7.67
LGA	DCA	1541	105.0	4.00	D9S	7	28200.	.52	7.67
LGA	JAX	153	627.0	9.00	D9S	7	35000.	1.22	14.94
LGA	MIA	11	865.0	7.00	72S	5	35000.	.92	17.50
LGA	MIA	11	865.0	7.00	72S	1	35000.	.92	17.50
LGA	MIA	11	865.0	7.00	727	1	35000.	.91	16.03
LGA	MIA	17	865.0	7.00	L10	7	41000.	.87	31.25
LGA	MIA	21	865.0	7.00	727	6	35000.	.91	16.03
LGA	MIA	29	865.0	7.00	L10	7	41000.	.87	31.25
LGA	MIA	415	865.0	7.00	L10	7	41000.	.87	31.25
LGA	PBI	193	803.0	7.00	72S	7	35000.	.92	17.50
LGA	PBI	475	803.0	7.00	D9S	7	35000.	.95	11.62
MEM	ATL	661	201.0	-1.00	D9S	7	31960.	-.13	-1.76
MEM	ATL	665	201.0	-1.00	DC9	7	31960.	-.13	-1.66

TABLE G.2

EASTERN AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
MEM	ATL	981	201.0	-1.00	72S	7	32253.	-.13	-2.65
MEM	ATL	983	201.0	-1.00	727	7	32253.	-.13	-2.42
MIA	ATL	252	453.0	23.00	D9S	7	35000.	3.11	39.17
MIA	ATL	452	453.0	23.00	727	7	35000.	3.00	52.66
MIA	ATL	564	453.0	23.00	72S	6	35000.	3.04	57.50
MIA	ATL	564	453.0	23.00	72S	1	35000.	3.04	57.50
MIA	ATL	602	453.0	23.00	727	7	35000.	3.00	52.66
MIA	ATL	616	453.0	23.00	72S	7	35000.	3.04	57.50
MIA	ATL	678	453.0	23.00	727	7	35000.	3.00	52.66
MIA	BAL	172	762.0	6.00	72S	7	35000.	.79	15.00
MIA	BDL	182	977.0	9.00	72S	7	35000.	1.19	22.50
MIA	BOS	42	1081.0	9.00	727	7	35000.	1.17	20.61
MIA	BOS	46	1081.0	9.00	72S	7	35000.	1.19	22.50
MIA	BOS	418	1081.0	9.00	727	7	35000.	1.17	20.61
MIA	CMH	302	814.0	7.00	727	7	35000.	.91	16.03
MIA	DCA	158	747.0	6.00	727	5	35000.	.78	13.74
MIA	DCA	158	747.0	6.00	D9S	2	35000.	.81	9.96
MIA	DCA	176	747.0	6.00	727	7	35000.	.78	13.74
MIA	DCA	190	747.0	6.00	D9S	7	35000.	.81	9.96
MIA	DCA	192	747.0	6.00	72S	7	35000.	.79	15.00
MIA	DCA	198	747.0	6.00	D9S	7	35000.	.81	9.96
MIA	DFW	976	326.0	11.00	727	7	35000.	1.43	25.19
MIA	DTW	422	924.0	8.00	727	7	35000.	1.04	18.32
MIA	DTW	952	924.0	8.00	L10	7	41000.	.99	35.71
MIA	EWR	4	889.0	7.00	72S	7	35000.	.92	17.50
MIA	EWR	6	889.0	7.00	D9S	7	35000.	.95	11.62
MIA	EWR	8	889.0	7.00	72S	7	35000.	.92	17.50
MIA	EWR	402	889.0	7.00	72S	7	35000.	.92	17.50
MIA	JFK	14	881.0	8.00	727	7	35000.	1.04	18.32
MIA	JFK	18	881.0	8.00	727	7	35000.	1.04	18.32
MIA	JFK	[illegible]	881.0	8.00	D9S	7	35000.	1.08	13.28
MIA	JFK	26	881.0	8.00	L10	7	41000.	.99	35.71
MIA	JFK	400	881.0	8.00	L10	7	41000.	.99	35.71
MIA	LGA	16	892.0	7.00	L10	7	41000.	.87	31.25
MIA	LGA	20	892.0	7.00	72S	6	35000.	.92	17.50
MIA	LGA	20	892.0	7.00	727	1	35000.	.91	16.03
MIA	LGA	24	892.0	7.00	727	7	35000.	.91	16.03
MIA	LGA	28	892.0	7.00	727	6	35000.	.91	16.03
MIA	LGA	414	892.0	7.00	L10	7	41000.	.87	31.25
MIA	LGA	892	892.0	7.00	L10	7	41000.	.87	31.25
MIA	MSY	524	509.0	2.00	D9S	7	35000.	.27	3.32
MIA	MSY	907	509.0	2.00	72S	7	35000.	.26	5.00
MIA	ORD	72	959.0	8.00	727	7	35000.	1.04	18.32
MIA	ORD	78	959.0	8.00	727	7	35000.	1.04	18.32
MIA	ORD	430	959.0	8.00	727	7	35000.	1.04	18.32
MIA	PHL	34	820.0	7.00	727	7	35000.	.91	16.03
MIA	PHL	36	820.0	7.00	727	7	35000.	.91	16.03
MIA	PHL	410	820.0	7.00	72S	7	35000.	.92	17.50
MIA	PHL	956	820.0	7.00	L10	7	41000.	.87	31.25
MIA	PIT	300	811.0	6.00	72S	7	35000.	.79	15.00
MIA	PIT	482	811.0	6.00	D9S	7	35000.	.81	9.96
MIA	STL	222	861.0	7.00	D9S	7	35000.	.95	11.62
MIA	STL	690	861.0	7.00	D9S	7	35000.	.95	11.62
MIA	TPA	614	90.0	-4.00	D9S	7	27000.	-.52	-7.92
MIA	TPA	672	90.0	-4.00	D9S	7	27000.	-.52	-7.92
MKE	ATL	787	518.0	25.00	D9S	7	35000.	3.38	41.49
MKE	ATL	789	518.0	25.00	727	7	35000.	3.26	57.24
MSY	ATL	108	288.0	0.00	727	7	35000.	0.00	0.00
MSY	ATL	428	288.0	0.00	727	7	35000.	0.00	0.00
MSY	ATL	566	288.0	0.00	D9S	7	33480.	0.00	0.00
MSY	ATL	634	288.0	0.00	72S	7	35000.	0.00	0.00
MSY	ATL	780	288.0	0.00	DC9	7	33480.	0.00	0.00
MSY	JFK	66	961.0	8.00	727	7	35000.	1.04	18.32
MSY	MIA	521	505.0	7.00	727	7	35000.	.91	16.03
MSY	MIA	906	505.0	7.00	727	7	35000.	.91	16.03
OKC	DEN	980	365.0	20.00	727	7	35000.	2.61	45.79
ORD	ATL	241	435.0	17.00	D9S	7	34950.	2.30	28.24
ORD	ATL	234	435.0	17.00	D9S	7	34950.	2.30	28.24
ORD	ATL	245	435.0	17.00	727	7	35000.	2.22	38.92
ORD	ATL	247	435.0	17.00	DC9	7	34950.	2.25	26.66
ORD	ATL	249	435.0	17.00	D9S	7	34950.	2.30	28.24
ORD	ATL	957	435.0	17.00	L10	7	40840.	2.10	76.26
ORD	BHM	225	409.0	3.00	DC9	7	34690.	.40	4.73
ORD	BNA	257	254.0	1.00	727	7	34560.	.13	2.31
ORD	BNA	891	254.0	1.00	DC9	7	33140.	.13	1.62
ORD	CLT	215	443.0	20.00	D9S	7	35000.	2.70	33.19
ORD	CLT	217	443.0	20.00	D9S	7	35000.	2.70	33.19
ORD	CLT	227	443.0	20.00	D9S	7	35000.	2.70	33.19
ORD	DTW	803	163.0	1.00	727	1	26040.	.13	2.77
ORD	FLL	469	960.0	8.00	D9S	7	35000.	1.08	13.28
ORD	FLL	791	960.0	8.00	727	7	35000.	1.04	18.32
ORD	FLL	795	960.0	8.00	727	7	35000.	1.04	18.32
ORD	GSO	207	-0.0	0.00	DC9	7	18200.	0.00	0.00
ORD	GSO	209	-0.0	0.00	DC9	7	18200.	0.00	0.00
ORD	MIA	75	953.0	8.00	727	7	35000.	1.04	18.32
ORD	MIA	79	953.0	8.00	72S	7	35000.	1.06	20.00
ORD	MIA	433	953.0	8.00	72S	5	35000.	1.06	20.00
ORD	MIA	433	953.0	8.00	727	2	35000.	1.04	18.32
ORD	MIA	993	953.0	8.00	727	7	35000.	1.04	18.32
ORD	RDU	203	507.0	48.00	D9S	7	35000.	6.49	79.67
ORD	RDU	205	507.0	48.00	DC9	7	35000.	6.34	75.20
ORD	TPA	237	804.0	6.00	727	7	35000.	.78	13.74
ORD	TPA	259	804.0	6.00	727	7	35000.	.78	13.74
ORD	TPA	437	804.0	6.00	D9S	7	35000.	.81	9.96
PBI	ATL	106	391.0	0.00	727	7	35000.	0.00	0.00
PBI	ATL	142	391.0	0.00	72S	7	35000.	0.00	0.00
PBI	ATL	242	391.0	0.00	72S	7	35000.	0.00	0.00
PBI	ATL	632	391.0	0.00	72S	7	35000.	0.00	0.00
PBI	JFK	194	877.0	8.00	72S	7	35000.	1.06	20.00
PBI	JFK	196	877.0	8.00	L10	7	41000.	.99	35.71
PBI	JFK	440	877.0	8.00	727	7	35000.	1.04	18.32
PBI	LGA	[illegible]	823.0	7.00	D9S	7	35000.	.95	11.62
PHL	ATL	121	500.0	9.00	727	7	35000.	1.17	20.61
PHL	ATL	123	500.0	9.00	727	7	35000.	1.17	20.61
PHL	ATL	125	500.0	9.00	727	7	35000.	1.17	20.61
PHL	ATL	127	500.0	9.00	727	7	35000.	1.17	20.61
PHL	ATL	449	500.0	9.00	L10	7	41000.	1.11	40.17
PHL	ATL	561	500.0	9.00	72S	7	35000.	1.19	22.50
PHL	BOS	556	208.0	43.00	727	7	32627.	5.55	103.53
PHL	BUF	646	210.0	53.00	727	7	32733.	6.85	127.47
PHL	CLT	373	329.0	21.00	D9S	7	33890.	2.82	35.55
PHL	CLT	379	329.0	21.00	D9S	7	33890.	2.82	35.55
PHL	CLT	579	329.0	21.00	D9S	7	33890.	2.82	35.55
PHL	CLT	603	329.0	21.00	D9S	7	33890.	2.82	35.55
PHL	MIA	35	816.0	7.00	L10	7	41000.	.87	31.25
PHL	MIA	37	816.0	7.00	727	7	35000.	.91	16.03
PHL	MIA	39	816.0	7.00	727	7	35000.	.91	16.03
PHL	MIA	411	816.0	7.00	727	7	35000.	.91	16.03
PHL	MSY	575	-0.0	0.00	727	7	12600.	0.00	0.00
PIT	ATL	327	388.0	19.00	D9S	7	34480.	2.56	31.83
PIT	ATL	329	388.0	19.00	72S	7	35000.	2.51	47.50
PIT	ATL	989	388.0	19.00	72S	7	35000.	2.51	47.50
PIT	CLT	311	235.0	3.00	72S	7	33800.	.39	7.71
PIT	CLT	317	235.0	3.00	D9S	7	32867.	.40	5.17
PIT	CLT	341	235.0	3.00	727	7	33800.	.39	7.06
PIT	CLT	349	235.0	3.00	D9S	7	32867.	.40	5.17
PIT	FLL	309	810.0	17.00	727	7	35000.	2.22	38.92
PIT	MIA	303	809.0	6.00	72S	7	35000.	.79	15.00
PIT	MIA	483	809.0	6.00	727	5	35000.	.78	13.74
PIT	MIA	483	809.0	6.00	D9S	2	35000.	.81	9.96
RDU	ATL	219	223.0	2.00	727	7	33320.	.26	4.76
RDU	ATL	361	223.0	2.00	72S	6	33320.	.26	5.19
RDU	ATL	361	223.0	2.00	72S	1	33320.	.26	5.19
RDU	ATL	393	223.0	2.00	727	7	33320.	.26	4.76
RDU	ATL	549	223.0	2.00	72S	7	33320.	.26	5.19
RDU	ATL	585	223.0	2.00	72S	5	33320.	.26	5.19
RDU	ATL	585	223.0	2.00	727	2	33320.	.26	4.76
RDU	ORD	204	489.0	0.00	D9S	7	35000.	0.00	0.00
RDU	ORD	208	489.0	0.00	D9S	7	35000.	0.00	0.00
RIC	LGA	562	146.0	0.00	727	7	29320.	0.00	0.00
RIC	LGA	898	146.0	0.00	D9S	7	30240.	0.00	0.00
SDF	ATL	261	203.0	12.00	DC9	7	32013.	1.56	19.87
SDF	ATL	265	203.0	12.00	D9S	7	32013.	1.60	21.05
SDF	ATL	269	203.0	12.00	DC9	7	32013.	1.56	19.87
SDF	ATL	435	203.0	12.00	D9S	7	32013.	1.60	21.05
SDF	ATL	653	203.0	12.00	D9S	7	32013.	1.60	21.05
SDF	DCA	254	321.0	12.00	D9S	7	33810.	1.61	20.34
SDF	DCA	508	321.0	12.00	72S	7	35000.	1.58	30.00
STL	ATL	97	334.0	1.00	727	7	35000.	.13	2.29
STL	ATL	99	334.0	1.00	L10	7	37608.	.12	4.93
STL	ATL	271	334.0	1.00	D9S	7	33940.	.13	1.69
STL	ATL	273	334.0	1.00	D9S	7	33940.	.13	1.69
STL	ATL	289	334.0	1.00	72S	7	35000.	.13	2.50
STL	ATL	699	334.0	1.00	D9S	7	33940.	.13	1.69
STL	DCA	510	532.0	4.00	D9S	7	35000.	.54	6.64
TPA	ATL	280	301.0	35.00	D9S	7	33610.	4.70	59.54
TPA	ATL	476	301.0	35.00	72S	7	35000.	4.62	87.51
TPA	ATL	488	301.0	35.00	727	7	35000.	4.57	80.13
TPA	ATL	546	301.0	35.00	72S	7	35000.	4.62	87.51
TPA	ATL	572	301.0	35.00	72S	7	35000.	4.62	87.51
TPA	ATL	624	301.0	35.00	72S	7	35000.	4.62	87.51

TABLE G.2
EASTERN AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
TPA	ATL	476	301.0	35.00	725	7	35000.	4.62	87.51
TPA	ATL	488	301.0	35.00	727	7	35000.	4.57	80.13
TPA	ATL	546	301.0	35.00	725	7	35000.	4.62	87.51
TPA	ATL	572	301.0	35.00	725	7	35000.	4.62	87.51
TPA	ATL	624	301.0	35.00	725	7	35000.	4.62	87.51
TPA	CLE	316	728.0	5.00	D95	7	35000.	.68	8.30
TPA	DTW	340	797.0	7.00	D95	7	35000.	.95	11.62
TPA	DTW	344	797.0	7.00	D95	7	35000.	.95	11.62
TPA	DTW	464	797.0	7.00	D95	7	35000.	.95	11.62
TPA	EWR	168	816.0	6.00	L10	7	41000.	.74	26.78
TPA	FLL	189	103.0	18.00	725	7	26040.	2.29	54.43
TPA	FLL	223	103.0	18.00	D95	7	28040.	2.36	34.67
TPA	FLL	339	103.0	18.00	D95	7	28040.	2.36	34.67
TPA	FLL	485	103.0	18.00	725	7	26040.	2.29	54.43
TPA	FLL	529	103.0	18.00	DC9	7	28040.	2.31	32.73
TPA	JFK	160	928.0	8.00	727	7	35000.	1.04	18.32
TPA	JFK	162	928.0	8.00	727	7	35000.	1.04	18.32
TPA	JFK	426	928.0	8.00	727	7	35000.	1.04	18.32
TPA	MIA	127	103.0	18.00	727	7	26040.	2.27	49.84
TPA	MIA	437	103.0	18.00	D95	7	28040.	2.36	34.67
TPA	MIA	645	103.0	18.00	725	6	26040.	2.29	54.43
TPA	MIA	645	103.0	18.00	725	1	26040.	2.29	54.43
TPA	ORD	230	793.0	6.00	727	7	35000.	.78	13.74
TPA	ORD	262	793.0	6.00	DC9	7	35000.	.79	9.40
TPA	ORD	466	793.0	6.00	727	7	35000.	.78	13.74

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE

TABLE G.3
DELTA AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
ATL	BAL	500	388.0	14.00	D9S	7	34480.	1.89	23.45
ATL	BAL	610	388.0	14.00	D9S	7	34480.	1.89	23.45
ATL	BAL	622	388.0	14.00	D9S	7	34480.	1.89	23.45
ATL	BAL	628	388.0	14.00	D9S	7	34480.	1.89	23.45
ATL	BAL	684	388.0	14.00	D9S	7	34480.	1.89	23.45
ATL	BAL	790	388.0	14.00	D9S	7	34480.	1.89	23.45
ATL	CAE	126	91.0	14.00	72S	7	25080.	1.78	43.61
ATL	CAE	308	91.0	14.00	72S	7	25080.	1.78	43.61
ATL	CAE	320	91.0	14.00	72S	7	25080.	1.78	43.61
ATL	CAE	406	91.0	14.00	72S	7	25080.	1.78	43.61
ATL	CAE	637	91.0	14.00	D9S	7	27080.	1.83	27.65
ATL	CAE	787	91.0	14.00	D9S	7	27080.	1.83	27.65
ATL	CAE	907	91.0	14.00	D8S	7	25080.	1.73	69.01
ATL	CLT	326	116.0	8.00	72S	7	27080.	1.02	23.41
ATL	CLT	520	116.0	8.00	D9S	7	29040.	1.05	15.01
ATL	CLT	620	116.0	8.00	D9S	7	29040.	1.05	15.01
ATL	CLT	818	116.0	8.00	D8F	7	27080.	.99	33.90
ATL	CLT	1116	116.0	8.00	72S	7	27080.	1.02	23.41
ATL	CLT	1126	116.0	8.00	D9S	7	29040.	1.05	15.01
ATL	DCA	124	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DCA	208	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DCA	210	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DCA	214	388.0	3.00	72S	6	35000.	.40	7.50
ATL	DCA	222	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DCA	288	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DCA	302	388.0	3.00	72S	7	35000.	.40	7.50
ATL	DCA	775	388.0	3.00	D9S	7	34480.	.40	5.03
ATL	DFW	15	555.0	1.00	747	7	37000.	.13	6.89
ATL	DFW	21	555.0	1.00	747	7	37000.	.13	6.89
ATL	DFW	783	555.0	1.00	D9S	7	35000.	.14	1.66
ATL	DFW	819	555.0	1.00	D8F	7	41000.	.13	4.20
ATL	DFW	821	555.0	1.00	D8F	7	41000.	.13	4.20
ATL	DFW	919	555.0	1.00	D8S	7	41000.	.13	4.59
ATL	DFW	1019	555.0	1.00	L10	7	41000.	.12	4.46
ATL	DFW	1197	555.0	1.00	L10	7	41000.	.12	4.46
ATL	DFW	1885	555.0	1.00	D8F	7	41000.	.13	4.20
ATL	DTW	148	555.0	1.00	72S	7	35000.	.13	2.50
ATL	DTW	448	555.0	1.00	72S	7	35000.	.13	2.50
ATL	DTW	1146	555.0	1.00	L10	7	41000.	.12	4.46
ATL	DTW	1198	555.0	1.00	L10	7	41000.	.12	4.46
ATL	EWR	116	585.0	4.00	72S	7	35000.	.53	10.00
ATL	EWR	384	585.0	4.00	72S	7	35000.	.53	10.00
ATL	EWR	920	585.0	4.00	D8S	6	41000.	.52	18.37
ATL	JAX	135	146.0	-6.00	72S	7	29320.	-.77	-16.56
ATL	JAX	289	146.0	-6.00	72S	7	29320.	-.77	-16.56
ATL	JAX	343	146.0	-6.00	72S	7	29320.	-.77	-16.56
ATL	JAX	411	146.0	-6.00	72S	7	29320.	-.77	-16.56
ATL	JAX	1089	146.0	-6.00	L10	7	29320.	-.72	-33.34
ATL	JAX	1095	146.0	-6.00	L10	7	29320.	-.72	-33.34
ATL	JAX	1110	146.0	-6.00	L10	7	29320.	-.72	-33.34
ATL	JFK	516	691.0	4.00	D9S	7	35000.	.54	6.64
ATL	JFK	924	691.0	4.00	D8S	7	41000.	.52	18.37
ATL	JFK	1089	691.0	4.00	L10	7	41000.	.49	17.85
ATL	LAX	825	1642.0	17.00	D8F	7	41000.	2.19	71.42
ATL	LAX	1117	1642.0	17.00	L10	7	41000.	2.10	75.88
ATL	LAX	1187	1642.0	17.00	L10	7	41000.	2.10	75.88
ATL	LAX	1215	1642.0	17.00	727	5	35000.	2.22	38.92
ATL	LGA	120	567.0	4.00	72S	7	35000.	.53	10.00
ATL	LGA	128	567.0	4.00	72S	7	35000.	.53	10.00
ATL	LGA	136	567.0	4.00	72S	7	35000.	.53	10.00
ATL	LGA	188	567.0	4.00	72S	7	35000.	.53	10.00
ATL	LGA	200	567.0	4.00	72S	7	35000.	.53	10.00
ATL	LGA	212	567.0	4.00	72S	7	35000.	.53	10.00
ATL	MEM	211	217.0	12.00	72S	7	33080.	1.57	31.34
ATL	MEM	240	217.0	12.00	72S	7	33080.	1.57	31.34
ATL	MEM	387	217.0	12.00	72S	7	33080.	1.57	31.34
ATL	MEM	450	217.0	12.00	72S	7	33080.	1.57	31.34
ATL	MEM	462	217.0	12.00	72S	7	33080.	1.57	31.34
ATL	MEM	617	217.0	12.00	D9S	6	32387.	1.60	20.89
ATL	MEM	690	217.0	12.00	D9S	7	32387.	1.60	20.89
ATL	MEM	1148	217.0	12.00	L10	7	33080.	1.46	62.60
ATL	MIA	149	470.0	41.00	72S	7	35000.	5.41	102.51
ATL	MIA	239	470.0	41.00	72S	7	35000.	5.41	102.51
ATL	MIA	335	470.0	41.00	72S	7	35000.	5.41	102.51
ATL	MIA	989	470.0	41.00	D8S	7	41000.	5.30	188.29
ATL	MIA	993	470.0	41.00	D8S	7	41000.	5.30	188.29
ATL	MIA	1131	470.0	41.00	L10	7	41000.	5.07	183.01
ATL	MIA	1145	470.0	41.00	L10	7	41000.	5.07	183.01
ATL	MSY	119	288.0	4.00	72S	7	35000.	.53	10.00
ATL	MSY	231	288.0	4.00	72S	7	35000.	.53	10.00
ATL	MSY	325	288.0	4.00	72S	7	35000.	.53	10.00
ATL	MSY	327	288.0	4.00	72S	7	35000.	.53	10.00
ATL	MSY	687	288.0	4.00	D9S	7	33480.	.54	6.82
ATL	MSY	917	288.0	4.00	D8S	7	35920.	.51	17.01
ATL	MSY	929	288.0	4.00	D8S	7	35920.	.51	17.01
ATL	MSY	957	288.0	4.00	D8S	6	35920.	.51	17.01
ATL	ORD	132	424.0	-2.00	72S	7	35000.	-.26	-5.00
ATL	ORD	138	424.0	-2.00	72S	7	35000.	-.26	-5.00
ATL	ORD	192	424.0	-2.00	72S	7	35000.	-.26	-5.00
ATL	ORD	234	424.0	-2.00	72S	7	35000.	-.26	-5.00
ATL	ORD	238	424.0	-2.00	72S	7	35000.	-.26	-5.00
ATL	ORD	1138	424.0	-2.00	L10	7	40488.	-.25	-9.07
ATL	ORD	1196	424.0	-2.00	L10	7	40488.	-.25	-9.07
ATL	PBI	249	389.0	-39.00	72S	7	35000.	-5.15	-97.51
ATL	PBI	267	389.0	-39.00	72S	7	35000.	-5.15	-97.51
ATL	PBI	493	389.0	-39.00	72S	7	35000.	-5.15	-97.51
ATL	PBI	737	389.0	-39.00	D9S	7	34490.	-5.26	-65.32
ATL	PHL	280	506.0	13.00	72S	7	35000.	1.72	32.50
ATL	PHL	316	506.0	13.00	72S	7	35000.	1.72	32.50
ATL	PHL	318	506.0	13.00	72S	7	35000.	1.72	32.50
ATL	PHL	324	506.0	13.00	72S	7	35000.	1.72	32.50
ATL	PHL	522	506.0	13.00	D9S	7	35000.	1.76	21.58
ATL	PHL	1124	506.0	13.00	L10	7	41000.	1.61	58.03
ATL	SAV	233	116.0	18.00	72S	7	27080.	2.30	52.66
ATL	SAV	305	116.0	18.00	72S	7	27080.	2.30	52.66
ATL	SAV	331	116.0	18.00	72S	7	27080.	2.30	52.66
ATL	SAV	345	116.0	18.00	72S	7	27080.	2.30	52.66
ATL	SAV	657	116.0	18.00	D9S	7	29040.	2.37	33.77
ATL	SAV	802	116.0	18.00	D8F	7	27080.	2.23	76.28
ATL	SDF	248	190.0	-3.00	72S	7	31667.	-.39	-8.00
ATL	SDF	278	190.0	-3.00	72S	7	31667.	-.39	-8.00
ATL	SDF	483	190.0	-3.00	72S	7	31667.	-.39	-8.00
ATL	SDF	596	190.0	-3.00	D9S	7	31667.	-.40	-5.30
ATL	SDF	632	190.0	-3.00	D9S	7	31667.	-.40	-5.30
ATL	SDF	642	190.0	-3.00	D9S	7	31667.	-.40	-5.30
ATL	SFO	923	1800.0	20.00	D8S	7	41000.	2.58	91.85
ATL	SFO	1191	1800.0	20.00	L10	7	41000.	2.47	89.27
ATL	TPA	141	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	287	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	355	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	447	277.0	11.00	72S	7	35000.	1.45	27.50
ATL	TPA	991	277.0	11.00	D8S	7	35480.	1.41	46.65
ATL	TPA	1139	277.0	11.00	L10	7	35480.	1.35	56.05
ATL	TPA	1147	277.0	11.00	L10	7	35480.	1.35	56.05
ATL	TPA	1151	277.0	11.00	L10	7	35480.	1.35	56.05
BAL	ATL	315	387.0	9.00	72S	7	35000.	1.19	22.50
BAL	ATL	505	387.0	9.00	D9S	7	34470.	1.21	15.08
BAL	ATL	601	387.0	9.00	D9S	7	34470.	1.21	15.08
BAL	ATL	699	387.0	9.00	D9S	7	34470.	1.21	15.08
BAL	ATL	705	387.0	9.00	D9S	7	34470.	1.21	15.08
BAL	BOS	500	261.0	17.00	D9S	7	33210.	2.28	29.12
BAL	BOS	790	261.0	17.00	D9S	7	33210.	2.28	29.12
BHM	JAN	303	107.0	12.00	72S	7	26360.	1.53	35.92
BHM	JAN	397	107.0	12.00	72S	7	26360.	1.53	35.92
BHM	JAN	629	107.0	12.00	D9S	7	28360.	1.57	22.92
BHM	JAN	1227	107.0	12.00	727	7	26360.	1.51	32.89
BHM	ORD	542	434.0	30.00	D9S	7	34940.	4.05	49.84
BNA	ORD	566	258.0	6.00	D9S	6	33180.	.80	10.28
BNA	ORD	568	258.0	6.00	D9S	7	33180.	.80	10.28
BNA	ORD	668	258.0	6.00	D9S	7	33180.	.80	10.28
BNA	ORD	760	258.0	6.00	D9S	7	33180.	.80	10.28
BOS	BAL	315	243.0	-1.00	72S	7	34120.	-.13	-2.55
BOS	BAL	711	243.0	-1.00	D9S	6	33030.	-.13	-1.72
BOS	DCA	215	244.0	0.00	72S	7	34160.	0.00	0.00
BOS	DCA	231	244.0	0.00	72S	7	34160.	0.00	0.00
BOS	DCA	275	244.0	0.00	72S	6	34160.	0.00	0.00
BOS	DCA	303	244.0	0.00	72S	7	34160.	0.00	0.00
BOS	DCA	311	244.0	0.00	72S	7	34160.	0.00	0.00
BOS	DCA	323	244.0	0.00	72S	7	34160.	0.00	0.00
BOS	DCA	325	244.0	0.00	72S	7	34160.	0.00	0.00
BOS	JFK	175	76.0	17.00	72S	7	23880.	2.20	53.83
BOS	JFK	389	76.0	17.00	72S	7	23880.	2.20	53.83
BOS	MIA	129	1030.0	0.00	72S	7	35000.	0.00	0.00
BOS	MIA	197	1030.0	0.00	72S	7	35000.	0.00	0.00
BOS	MIA	375	1030.0	0.00	72S	7	35000.	0.00	0.00
BOS	PHL	219	195.0	35.00	72S	7	31933.	4.56	93.02
BOS	PHL	261	195.0	35.00	72S	7	31933.	4.56	93.02
BOS	PHL	273	195.0	35.00	72S	7	31933.	4.56	93.02
BOS	PHL	481	195.0	35.00	72S	6	31933.	4.56	93.02
BOS	PHL	534	195.0	35.00	D9S	6	31800.	4.66	61.65
BOS	PHL	577	195.0	35.00	D9S	7	31800.	4.65	61.65
CLT	JFK	326	390.0	25.00	72S	7	35000.	3.30	[illegible]
CLT	JFK	520	390.0	25.00	D9S	7	34500.	3.37	41.87
DAY	ATL	241	382.0	8.00	72S	7	35000.	1.06	20.00
DAY	ATL	339	382.0	8.00	72S	7	35000.	1.06	20.00
DAY	ATL	773	382.0	8.00	D9S	7	34420.	1.08	13.42
DAY	ATL	785	382.0	8.00	D9S	7	34420.	1.08	13.42

TABLE G.3
DELTA AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
DAY	ATL	789	382.0	8.00	D9S	7	34420.	1.08	13.42
DAY	ATL	1147	382.0	8.00	L10	7	39144.	.99	37.77
DCA	BOS	208	261.0	17.00	72S	7	34840.	2.24	42.66
DCA	BOS	210	261.0	17.00	72S	7	34840.	2.24	42.66
DCA	BOS	214	261.0	17.00	72S	6	34840.	2.24	42.66
DCA	BOS	222	261.0	17.00	72S	7	34840.	2.24	42.66
DCA	BOS	230	261.0	17.00	72S	7	34840.	2.24	42.66
DCA	BOS	288	261.0	17.00	72S	7	34840.	2.24	42.66
DCA	BOS	302	261.0	17.00	72S	7	34840.	2.24	42.66
DCA	BOS	775	261.0	17.00	D9S	7	33210.	2.28	29.12
DFW	ATL	16	563.0	4.00	747	7	37000.	.50	27.58
DFW	ATL	126	563.0	4.00	72S	7	35000.	.53	10.00
DFW	ATL	704	563.0	4.00	D9S	7	35000.	.54	6.64
DFW	ATL	820	563.0	4.00	D8F	7	41000.	.51	16.81
DFW	ATL	884	563.0	4.00	D8F	7	41000.	.51	16.81
DFW	ATL	986	563.0	4.00	D8S	5	41000.	.52	18.37
DFW	ATL	1110	563.0	4.00	L10	7	41000.	.49	17.85
DFW	ATL	1116	563.0	4.00	L10	7	41000.	.49	17.85
DFW	ATL	1124	563.0	4.00	L10	7	41000.	.49	17.85
DFW	LAX	21	999.0	0.00	747	7	37000.	0.00	0.00
DFW	LAX	917	999.0	0.00	D8S	7	41000.	0.00	0.00
DFW	LAX	1125	999.0	0.00	L10	7	41000.	0.00	0.00
DFW	LAX	1197	999.0	0.00	L10	7	41000.	0.00	0.00
DFW	LAX	1227	999.0	0.00	727	7	35000.	0.00	0.00
DFW	LAX	1885	999.0	0.00	D8F	7	41000.	0.00	0.00
DFW	MSY	504	302.0	-4.00	D9S	7	33620.	-.54	-6.80
DFW	MSY	780	302.0	-4.00	D9S	7	33620.	-.54	-6.80
DFW	MSY	814	302.0	-4.00	D8F	7	36480.	-.51	-15.62
DFW	MSY	898	302.0	-4.00	D8F	7	36480.	-.51	-15.62
DFW	MSY	920	302.0	-4.00	D8S	6	36480.	-.52	-17.07
DFW	MSY	928	302.0	-4.00	D8S	7	36480.	-.52	-17.07
DFW	MSY	956	302.0	-4.00	D8S	1	36480.	-.52	-17.07
DFW	MSY	1080	302.0	-4.00	L10	7	36480.	-.49	-20.18
DFW	PHX	115	713.0	5.00	72S	7	35000.	.66	12.50
DFW	PHX	425	713.0	5.00	72S	7	35000.	.66	12.50
DFW	PHX	821	713.0	5.00	D8F	7	41000.	.64	21.01
DFW	SFO	819	1177.0	0.00	D8F	7	41000.	0.00	0.00
DFW	SFO	827	1177.0	0.00	D8F	7	41000.	0.00	0.00
DFW	SFO	1019	1177.0	0.00	L10	7	41000.	0.00	0.00
DFW	SFO	1021	1177.0	0.00	L10	7	41000.	0.00	0.00
DTW	ATL	411	449.0	0.00	72S	7	35000.	0.00	0.00
DTW	ATL	945	449.0	0.00	D8S	7	41000.	0.00	0.00
DTW	ATL	1043	449.0	0.00	L10	7	41000.	0.00	0.00
DTW	ATL	1095	449.0	0.00	L10	7	41000.	0.00	0.00
DTW	ORD	551	101.0	-4.00	D9S	5	27880.	-.52	-7.74
DTW	ORD	651	101.0	-4.00	D9S	7	27880.	-.52	-7.74
DTW	SDF	745	182.0	5.00	D9S	7	31453.	.67	8.87
DTW	TPA	951	-0.0	0.00	D8S	7	12600.	0.00	0.00
DTW	TPA	1185	-0.0	0.00	L10	7	12600.	0.00	0.00
EWR	ATL	119	569.0	4.00	72S	7	35000.	.53	10.00
EWR	ATL	517	569.0	4.00	D9S	7	35000.	.54	6.64
EWR	ATL	605	569.0	4.00	D9S	7	35000.	.54	6.64
EWR	ATL	617	569.0	4.00	D9S	6	35000.	.54	6.64
EWR	ATL	981	569.0	4.00	D8S	7	41000.	.52	18.37
EWR	CLT	425	377.0	6.00	72S	7	35000.	.79	15.00
EWR	FLL	173	868.0	7.00	72S	7	35000.	.92	17.50
EWR	FLL	189	868.0	7.00	72S	7	35000.	.92	17.50
EWR	FLL	437	868.0	7.00	72S	7	35000.	.92	17.50
EWR	MIA	1265	856.0	7.00	727	7	35000.	.91	16.03
FLL	BOS	220	1029.0	9.00	72S	7	35000.	1.19	22.50
FLL	BOS	490	1029.0	9.00	72S	7	35000.	1.19	22.50
FLL	BOS	1168	1029.0	9.00	L10	7	41000.	1.11	40.17
FLL	EWR	260	874.0	7.00	72S	7	35000.	.92	17.50
FLL	EWR	438	874.0	7.00	72S	7	35000.	.92	17.50
FLL	EWR	496	874.0	7.00	72S	7	35000.	.92	17.50
FLL	JFK	254	864.0	5.00	72S	7	35000.	.66	12.50
FLL	JFK	286	864.0	5.00	72S	7	35000.	.66	12.50
FLL	JFK	374	864.0	5.00	72S	7	35000.	.66	12.50
FLL	JFK	1072	864.0	5.00	L10	7	41000.	.62	22.32
FLL	ORD	388	957.0	8.00	72S	7	35000.	1.06	20.00
FLL	ORD	452	957.0	8.00	72S	7	35000.	1.06	20.00
FLL	ORD	458	957.0	8.00	72S	7	35000.	1.06	20.00
FLL	PHL	236	853.0	7.00	72S	7	35000.	.92	17.50
FLL	PHL	782	853.0	7.00	D9S	7	35000.	.95	11.62
FLL	TPA	1140	90.0	-4.00	L10	7	25000.	-.48	-24.47
GSO	ORD	543	434.0	0.00	D9S	7	34940.	0.00	0.00
GSO	ORD	554	434.0	0.00	D9S	7	34940.	0.00	0.00
IAD	ATL	107	390.0	12.00	D8F	5	39400.	1.54	49.05
IND	MEM	183	248.0	6.00	72S	7	34320.	.79	15.24
IND	MEM	615	248.0	6.00	D9S	6	33080.	.80	10.30
IND	MEM	633	248.0	6.00	D9S	7	33080.	.80	10.30
IND	MEM	671	248.0	6.00	D9S	7	33080.	.80	10.30
JAN	MEM	517	75.0	-1.00	D9S	7	26400.	-.13	-2.01
JAN	MEM	558	75.0	-1.00	D9S	7	26400.	-.13	-2.01
JAN	MEM	709	75.0	-1.00	D9S	7	26400.	-.13	-2.01
JAN	MEM	766	75.0	-1.00	D9S	7	26400.	-.13	-2.01
JAN	SHV	303	101.0	0.00	D9S	7	25880.	0.00	0.00
JAN	SHV	629	101.0	0.00	D9S	7	27880.	0.00	0.00
JAN	SHV	729	101.0	0.00	D9S	7	27880.	0.00	0.00
JAN	SHV	1227	101.0	0.00	727	7	25880.	0.00	0.00
JAX	ATL	412	148.0	2.00	72S	7	29427.	.26	5.51
JAX	ATL	448	148.0	2.00	72S	7	29427.	.26	5.51
JAX	ATL	936	148.0	2.00	D8S	7	29427.	.25	8.84
JAX	ATL	996	148.0	2.00	72S	7	29427.	.26	5.51
JAX	ATL	1019	148.0	2.00	L10	7	29427.	.24	11.09
JAX	ATL	1117	148.0	2.00	L10	7	29427.	.24	11.09
JAX	ATL	1196	148.0	2.00	L10	7	29427.	.24	11.09
JAX	MIA	1235	203.0	0.00	727	7	32360.	0.00	0.00
JFK	ATL	127	572.0	18.00	72S	7	35000.	2.38	45.00
JFK	ATL	389	572.0	18.00	72S	7	35000.	2.38	45.00
JFK	ATL	959	572.0	18.00	D8S	7	41000.	2.33	82.66
JFK	BOS	254	106.0	50.00	72S	7	26280.	6.37	150.04
JFK	FLL	175	888.0	7.00	72S	7	35000.	.92	17.50
JFK	FLL	369	888.0	7.00	72S	7	35000.	.92	17.50
JFK	FLL	1071	888.0	7.00	L10	7	41000.	.87	31.25
JFK	FLL	1081	888.0	7.00	L10	7	41000.	.87	31.25
JFK	MIA	193	874.0	0.00	72S	7	35000.	0.00	0.00
JFK	MIA	471	874.0	0.00	72S	7	35000.	0.00	0.00
JFK	MIA	479	874.0	0.00	72S	7	35000.	0.00	0.00
JFK	MSY	121	952.0	8.00	72S	7	35000.	1.06	20.00
JFK	MSY	489	952.0	8.00	72S	7	35000.	1.06	20.00
JFK	TPA	177	789.0	6.00	72S	7	35000.	.79	15.00
JFK	TPA	495	789.0	6.00	72S	7	35000.	.79	15.00
LAS	ATL	910	1594.0	10.00	D8S	5	41000.	1.29	45.92
LAS	SFO	911	293.0	0.00	D8S	5	36120.	0.00	0.00
LAX	DFW	898	991.0	0.00	D8F	7	41000.	0.00	0.00
LAX	DFW	922	991.0	0.00	D8S	7	41000.	0.00	0.00
LAX	DFW	1080	991.0	0.00	L10	7	41000.	0.00	0.00
LAX	DFW	1110	991.0	0.00	L10	7	41000.	0.00	0.00
LAX	DFW	1116	991.0	0.00	L10	7	41000.	0.00	0.00
LAX	DFW	1228	991.0	0.00	727	7	35000.	0.00	0.00
LAX	MSY	972	1386.0	14.00	D8S	7	41000.	1.81	64.29
LAX	MSY	984	1386.0	14.00	D8S	2	41000.	1.81	64.29
LAX	SFO	975	199.0	17.00	D8S	7	32147.	2.16	71.97
LAX	SFO	983	199.0	17.00	D8S	2	32147.	2.16	71.97
LGA	ATL	123	560.0	4.00	72S	7	35000.	.53	10.00
LGA	ATL	201	560.0	4.00	72S	7	35000.	.53	10.00
LGA	ATL	209	560.0	4.00	72S	6	35000.	.53	10.00
LGA	ATL	223	560.0	4.00	72S	7	35000.	.53	10.00
LGA	ATL	397	560.0	4.00	72S	7	35000.	.53	10.00
LGA	ATL	732	560.0	4.00	D9S	7	35000.	.54	6.64
LGA	BHM	629	654.0	5.00	D9S	7	35000.	.68	8.30
LGA	CLT	327	387.0	16.00	72S	7	35000.	2.11	40.00
LGA	CLT	525	387.0	16.00	D9S	6	34470.	2.16	26.81
LGA	CLT	721	387.0	16.00	D9S	1	34470.	2.16	26.81
LGA	MIA	167	865.0	7.00	72S	7	35000.	.92	17.50
LGA	MIA	565	865.0	7.00	D9S	7	35000.	.95	11.62
MDW	STL	595	137.0	14.00	D9S	6	29880.	1.85	25.74
MEM	ATL	247	201.0	-1.00	72S	7	32253.	-.13	-2.65
MEM	ATL	363	201.0	-1.00	72S	7	32253.	-.13	-2.65
MEM	ATL	384	201.0	-1.00	72S	7	32253.	-.13	-2.65
MEM	ATL	475	201.0	-1.00	72S	7	32253.	-.13	-2.65
MEM	ATL	651	201.0	-1.00	D9S	7	31960.	-.13	-1.76
MEM	ATL	664	201.0	-1.00	D9S	7	31960.	-.13	-1.76
MEM	ATL	666	201.0	-1.00	D9S	7	31960.	-.13	-1.76
MEM	ATL	1139	201.0	-1.00	L10	7	32253.	-.12	-5.29
MEM	BHM	324	96.0	0.00	72S	7	25480.	0.00	0.00
MEM	BHM	671	96.0	0.00	D9S	7	27480.	0.00	0.00
MEM	IND	390	243.0	0.00	72S	7	34120.	0.00	0.00
MEM	IND	558	243.0	0.00	D9S	7	33030.	0.00	0.00
MEM	IND	762	243.0	0.00	D9S	7	33030.	0.00	0.00
MEM	IND	768	243.0	0.00	D9S	7	33030.	0.00	0.00
MEM	JAN	648	75.0	-1.00	D9S	7	26400.	-.13	-2.01
MEM	JAN	669	75.0	-1.00	D9S	7	26400.	-.13	-2.01
MEM	JAN	741	75.0	-1.00	D9S	7	26400.	-.13	-2.01
MEM	JAN	763	75.0	-1.00	D9S	7	26400.	-.13	-2.01
MEM	MSY	161	214.0	-4.00	72S	6	32947.	-.52	-10.47
MEM	MSY	295	214.0	-4.00	72S	7	32947.	-.52	-10.47
MEM	MSY	615	214.0	-4.00	D9S	6	32307.	-.53	-6.97
MEM	MSY	1133	214.0	-4.00	L10	7	32947.	-.49	-20.90

TABLE G.3
DELTA AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
MEM	ORD	517	322.0	1.00	D9S	7	33820.	.13	1.69
MEM	ORD	594	322.0	1.00	D9S	7	33820.	.13	1.69
MEM	ORD	725	322.0	1.00	D9S	7	33820.	.13	1.69
MEM	ORD	766	322.0	1.00	D9S	7	33820.	.13	1.69
MEM	ORD	1148	322.0	1.00	L10	7	37224.	.12	4.99
MEM	SHV	183	161.0	2.00	72S	7	30120.	.26	5.46
MEM	SHV	633	161.0	2.00	D9S	7	30840.	.27	3.59
MEM	SHV	761	161.0	2.00	D9S	7	30840.	.27	3.59
MEM	STL	562	132.0	4.00	D9S	7	29680.	.53	7.39
MEM	STL	574	132.0	4.00	D9S	6	29680.	.53	7.39
MEM	STL	617	132.0	4.00	D9S	6	29680.	.53	7.39
MEM	STL	670	132.0	4.00	D9S	7	29680.	.53	7.39
MEM	STL	690	132.0	4.00	D9S	7	29680.	.53	7.39
MEM	STL	709	132.0	4.00	D9S	7	29680.	.53	7.39
MGM	MSY	517	161.0	9.00	D9S	7	30840.	1.19	16.17
MGM	MSY	721	161.0	9.00	D9S	1	30840.	1.19	16.17
MIA	ATL	182	453.0	23.00	72S	7	35000.	3.04	57.50
MIA	ATL	456	453.0	23.00	72S	7	35000.	3.04	57.50
MIA	ATL	940	453.0	23.00	D8S	7	41000.	2.97	105.63
MIA	ATL	960	453.0	23.00	D8S	7	41000.	2.97	105.63
MIA	ATL	1056	453.0	23.00	L10	7	41000.	2.85	102.66
MIA	ATL	1090	453.0	23.00	L10	7	41000.	2.85	102.66
MIA	ATL	1122	453.0	23.00	L10	7	41000.	2.85	102.66
MIA	BOS	276	1081.0	9.00	72S	6	35000.	1.19	22.50
MIA	BOS	474	1081.0	9.00	72S	7	35000.	1.19	22.50
MIA	BOS	488	1081.0	9.00	72S	7	35000.	1.19	22.50
MIA	CMH	758	814.0	7.00	D9S	7	35000.	.95	11.62
MIA	DTW	354	924.0	8.00	72S	7	35000.	1.06	20.00
MIA	DTW	492	924.0	8.00	72S	7	35000.	1.06	20.00
MIA	EWR	358	889.0	7.00	72S	7	35000.	.92	17.50
MIA	JFK	298	881.0	8.00	72S	7	35000.	1.06	20.00
MIA	JFK	470	881.0	8.00	72S	7	35000.	1.06	20.00
MIA	JFK	472	881.0	8.00	72S	7	35000.	1.06	20.00
MIA	JFK	478	881.0	8.00	72S	7	35000.	1.06	20.00
MIA	LGA	174	892.0	7.00	72S	7	35000.	.92	17.50
MIA	ORD	142	959.0	8.00	72S	7	35000.	1.06	20.00
MIA	ORD	296	959.0	8.00	72S	7	35000.	1.06	20.00
MIA	ORD	1136	959.0	8.00	L10	7	41000.	.99	35.71
MIA	ORD	1250	959.0	8.00	727	7	35000.	1.04	18.32
MIA	PHL	168	820.0	7.00	72S	7	35000.	.92	17.50
MIA	PHL	1258	820.0	7.00	727	7	35000.	.91	16.03
MIA	TPA	140	90.0	-4.00	72S	7	25000.	-.51	-12.49
MIA	TPA	292	90.0	-4.00	72S	7	25000.	-.51	-12.49
MIA	TPA	546	90.0	-4.00	D9S	7	27000.	-.52	-7.92
MIA	TPA	1254	90.0	-4.00	727	7	25000.	-.50	-11.44
MSY	ATL	288	288.0	0.00	72S	7	35000.	0.00	0.00
MSY	ATL	320	288.0	0.00	72S	7	35000.	0.00	0.00
MSY	ATL	862	288.0	0.00	D8F	7	35920.	0.00	0.00
MSY	ATL	920	288.0	0.00	D8S	6	35920.	0.00	0.00
MSY	ATL	924	288.0	0.00	D8S	7	35920.	0.00	0.00
MSY	ATL	928	288.0	0.00	D8S	7	35920.	0.00	0.00
MSY	ATL	1080	288.0	0.00	L10	7	35920.	0.00	0.00
MSY	BAL	420	763.0	6.00	72S	7	35000.	.79	15.00
MSY	BAL	526	763.0	6.00	D9S	7	35000.	.81	9.96
MSY	DFW	115	304.0	4.00	72S	7	35000.	.53	10.00
MSY	DFW	325	304.0	4.00	72S	7	35000.	.53	10.00
MSY	DFW	691	304.0	4.00	D9S	7	33640.	.54	6.80
MSY	DFW	827	304.0	4.00	D8F	7	36560.	.51	15.63
MSY	DFW	903	304.0	4.00	D8S	6	36560.	.52	17.08
MSY	DFW	917	304.0	4.00	D8S	7	36560.	.52	17.08
MSY	DFW	955	304.0	4.00	D8S	1	36560.	.52	17.08
MSY	DFW	1021	304.0	4.00	L10	7	36560.	.49	20.17
MSY	JFK	122	961.0	8.00	72S	7	35000.	1.06	20.00
MSY	LAX	975	1354.0	13.00	D8S	7	41000.	1.68	59.70
MSY	LAX	983	1354.0	13.00	D8S	2	41000.	1.68	59.70
MSY	MEM	574	214.0	-2.00	D9S	6	32307.	-.27	-3.49
MSY	MEM	594	214.0	-2.00	D9S	7	32307.	-.27	-3.49
MSY	MEM	644	214.0	-2.00	D9S	7	32307.	-.27	-3.49
MSY	MEM	670	214.0	-2.00	D9S	7	32307.	-.27	-3.49
MSY	MEM	762	214.0	-2.00	D9S	7	32307.	-.27	-3.49
MSY	ORD	360	626.0	1.00	72S	7	35000.	.13	2.50
MSY	ORD	578	626.0	1.00	D9S	7	35000.	.14	1.66
MSY	ORD	814	626.0	1.00	D8F	7	41000.	.13	4.20
ORD	ATL	239	435.0	17.00	72S	7	35000.	2.24	42.50
ORD	ATL	287	435.0	17.00	72S	7	35000.	2.24	42.50
ORD	ATL	289	435.0	17.00	72S	7	35000.	2.24	42.50
ORD	ATL	345	435.0	17.00	72S	7	35000.	2.24	42.50
ORD	ATL	355	435.0	17.00	72S	7	35000.	2.24	42.50
ORD	ATL	749	435.0	17.00	D9S	7	34950.	2.30	28.24
ORD	ATL	1151	435.0	17.00	L10	7	40940.	2.10	76.26
ORD	BHM	563	409.0	3.00	D9S	7	34690.	.40	5.01
ORD	BNA	561	254.0	1.00	D9S	7	33140.	.13	1.72
ORD	BNA	567	254.0	1.00	D9S	7	33140.	.13	1.72
ORD	BNA	733	254.0	1.00	D9S	7	33140.	.13	1.72
ORD	BNA	767	254.0	1.00	D9S	7	33140.	.13	1.72
ORD	DTW	548	103.0	1.00	D9S	7	28040.	.13	1.93
ORD	DTW	550	103.0	1.00	D9S	5	28040.	.13	1.93
ORD	FLL	235	960.0	8.00	72S	7	35000.	1.06	20.00
ORD	FLL	359	960.0	8.00	72S	7	35000.	1.06	20.00
ORD	FLL	499	960.0	8.00	72S	7	35000.	1.06	20.00
ORD	GSO	507	-0.0	0.00	D9S	7	18200.	0.00	0.00
ORD	GSO	530	-0.0	0.00	D9S	7	18200.	0.00	0.00
ORD	MEM	295	323.0	-4.00	72S	7	35000.	-.53	-10.00
ORD	MEM	675	323.0	-4.00	D9S	7	33830.	-.54	-6.78
ORD	MEM	741	323.0	-4.00	D9S	7	33830.	-.54	-6.78
ORD	MEM	763	323.0	-4.00	D9S	7	33830.	-.54	-6.78
ORD	MEM	1133	323.0	-4.00	L10	7	37256.	-.49	-19.94
ORD	MEM	1139	323.0	-4.00	L10	7	37256.	-.49	-19.94
ORD	MIA	351	953.0	8.00	72S	7	35000.	1.06	20.00
ORD	MIA	431	953.0	8.00	72S	7	35000.	1.06	20.00
ORD	MIA	893	953.0	8.00	D8F	7	41000.	1.03	33.61
ORD	MIA	1135	953.0	8.00	L10	7	41000.	.99	35.71
ORD	RDU	533	507.0	48.00	D9S	7	35000.	6.49	79.67
ORD	RDU	543	507.0	48.00	D9S	7	35000.	6.49	79.67
ORD	STL	143	136.0	12.00	72S	7	28680.	1.54	33.58
ORD	STL	157	136.0	12.00	72S	7	28680.	1.54	33.58
ORD	STL	537	136.0	12.00	D9S	6	29840.	1.58	22.09
ORD	STL	591	136.0	12.00	D9S	6	29840.	1.58	22.09
ORD	STL	651	136.0	12.00	D9S	7	29840.	1.58	22.09
ORD	STL	653	136.0	12.00	D9S	6	29840.	1.58	22.09
ORD	STL	667	136.0	12.00	D9S	7	29840.	1.58	22.09
ORD	STL	669	136.0	12.00	D9S	7	29840.	1.58	22.09
ORD	STL	761	136.0	12.00	D9S	7	29840.	1.58	22.09
ORD	STL	771	136.0	12.00	D9S	7	29840.	1.58	22.09
ORD	TPA	251	804.0	6.00	72S	7	35000.	.79	15.00
ORD	TPA	487	804.0	6.00	72S	7	35000.	.79	15.00
PBI	ATL	278	391.0	0.00	72S	7	35000.	0.00	0.00
PBI	ATL	346	391.0	0.00	72S	7	35000.	0.00	0.00
PBI	ATL	396	391.0	0.00	72S	7	35000.	0.00	0.00
PBI	ATL	744	391.0	0.00	D9S	7	34510.	0.00	0.00
PHL	ATL	265	500.0	9.00	72S	7	35000.	1.19	22.50
PHL	ATL	317	500.0	9.00	72S	7	35000.	1.19	22.50
PHL	ATL	534	500.0	9.00	D9S	6	35000.	1.22	14.94
PHL	ATL	589	500.0	9.00	D9S	7	35000.	1.22	14.94
PHL	ATL	725	500.0	9.00	D9S	7	35000.	1.22	14.94
PHL	ATL	1189	500.0	9.00	L10	7	41000.	1.11	40.17
PHL	BOS	168	208.0	43.00	72S	7	32627.	5.62	113.11
PHL	BOS	270	208.0	43.00	72S	7	32627.	5.62	113.11
PHL	BOS	280	208.0	43.00	72S	7	32627.	5.62	113.11
PHL	BOS	310	208.0	43.00	72S	6	32627.	5.62	113.11
PHL	BOS	716	208.0	43.00	D9S	6	32147.	5.74	75.22
PHL	BOS	722	208.0	43.00	D9S	7	32147.	5.74	75.22
PHL	MIA	131	816.0	7.00	72S	7	35000.	.92	17.50
PHL	MIA	441	816.0	7.00	72S	7	35000.	.92	17.50
PHL	MSY	219	-0.0	0.00	72S	7	12600.	0.00	0.00
PHX	DFW	318	716.0	5.00	72S	7	35000.	.66	12.50
PHX	DFW	382	716.0	5.00	72S	7	35000.	.66	12.50
PHX	DFW	820	716.0	5.00	D8F	7	41000.	.64	21.01
RDU	ORD	530	489.0	0.00	D9S	7	35000.	0.00	0.00
RDU	ORD	569	489.0	0.00	D9S	7	35000.	0.00	0.00
SAV	ATL	202	101.0	3.00	72S	7	25880.	.38	9.12
SAV	ATL	234	101.0	3.00	72S	7	25880.	.38	9.12
SAV	ATL	238	101.0	3.00	72S	7	25880.	.38	9.12
SAV	ATL	305	101.0	3.00	72S	7	25880.	.38	9.12
SAV	ATL	309	101.0	3.00	72S	7	25880.	.38	9.12
SAV	ATL	387	101.0	3.00	72S	7	25880.	.38	9.12
SDF	ATL	135	203.0	12.00	72S	7	32360.	1.57	31.69
SDF	ATL	559	203.0	12.00	D9S	7	32013.	1.60	21.05
SDF	ATL	637	203.0	12.00	D9S	7	32013.	1.60	21.05
SDF	ATL	649	203.0	12.00	D9S	7	32013.	1.60	21.05
SDF	ATL	687	203.0	12.00	D9S	7	32013.	1.60	21.05
SDF	ATL	743	203.0	12.00	D9S	7	32013.	1.60	21.05
SDF	DTW	1254	189.0	11.00	727	7	31613.	1.41	26.90
SDF	ORD	258	144.0	-12.00	72S	7	29213.	-1.55	-33.17
SDF	ORD	278	144.0	-12.00	72S	7	29213.	-1.55	-33.17
SDF	ORD	642	144.0	-12.00	D9S	7	30160.	-1.59	-21.92
SDF	ORD	730	144.0	-12.00	D9S	7	30160.	-1.59	-21.92
SDF	ORD	754	144.0	-12.00	D9S	7	30160.	-1.59	-21.92
SFO	ATL	1096	1776.0	25.00	L10	7	41000.	3.09	111.59
SFO	ATL	1126	1776.0	25.00	L10	7	41000.	3.09	111.59

TABLE G.3
DELTA AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
SDF	ORD	730	144.0	-12.00	D9S	7	30160.	-1.59	-21.92
SDF	ORD	754	144.0	-12.00	D9S	7	30160.	-1.59	-21.92
SFO	ATL	1096	1776.0	25.00	L10	7	41000.	3.09	111.59
SFO	ATL	1126	1776.0	25.00	L10	7	41000.	3.09	111.59
SFO	DFW	814	1207.0	12.00	D8F	7	41000.	1.54	50.42
SFO	DFW	884	1207.0	12.00	D8F	7	41000.	1.54	50.42
SFO	DFW	928	1207.0	12.00	D8S	7	41000.	1.55	55.11
SFO	DFW	1124	1207.0	12.00	L10	7	41000.	1.48	53.56
SFO	LAS	986	278.0	29.00	D8S	5	35520.	3.73	123.02
SFO	LAX	972	182.0	3.00	D8S	7	31240.	.38	12.89
SFO	LAX	984	182.0	3.00	D8S	2	31240.	.38	12.89
SHV	JAN	188	102.0	1.00	72S	7	25960.	.13	3.03
SHV	JAN	392	102.0	1.00	72S	7	25960.	.13	3.03
SHV	JAN	524	102.0	1.00	D9S	7	27960.	.13	1.93
SHV	JAN	724	102.0	1.00	D9S	7	27960.	.13	1.93
SHV	JAN	1228	102.0	1.00	727	7	25960.	.13	2.78
STL	MDW	562	120.0	-2.00	D9S	7	29200.	-.26	-3.74
STL	MDW	770	120.0	-2.00	D9S	6	29200.	-.26	-3.74
STL	MEM	157	132.0	-1.00	72S	7	28360.	-.13	-2.82
STL	MEM	595	132.0	-1.00	D9S	6	29680.	-.13	-1.85
STL	MEM	651	132.0	-1.00	D9S	7	29680.	-.13	-1.85
STL	MEM	669	132.0	-1.00	D9S	7	29680.	-.13	-1.85
STL	MEM	761	132.0	-1.00	D9S	7	29680.	-.13	-1.85
STL	ORD	560	120.0	-2.00	D9S	7	29200.	-.26	-3.74
STL	ORD	570	120.0	-2.00	D9S	6	29200.	-.26	-3.74
STL	ORD	617	120.0	-2.00	D9S	6	29200.	-.26	-3.74
STL	ORD	630	120.0	-2.00	D9S	7	29200.	-.26	-3.74
STL	ORD	652	120.0	-2.00	D9S	7	29200.	-.26	-3.74
STL	ORD	662	120.0	-2.00	D9S	6	29200.	-.26	-3.74
STL	ORD	670	120.0	-2.00	D9S	7	29200.	-.26	-3.74
STL	ORD	690	120.0	-2.00	D9S	7	29200.	-.26	-3.74
STL	ORD	778	120.0	-2.00	D9S	7	29200.	-.26	-3.74
STL	ORD	796	120.0	-2.00	D9S	6	29200.	-.26	-3.74
TPA	ATL	450	301.0	35.00	72S	7	35000.	4.62	87.51
TPA	ATL	596	301.0	35.00	72S	7	35000.	4.62	87.51
TPA	ATL	952	301.0	35.00	D8S	7	36440.	4.51	149.33
TPA	ATL	1044	301.0	35.00	L10	7	36440.	4.32	176.67
TPA	ATL	1140	301.0	35.00	L10	7	36440.	4.32	176.67
TPA	ATL	1146	301.0	35.00	L10	7	36440.	4.32	176.67
TPA	ATL	1186	301.0	35.00	L10	7	36440.	4.32	176.67
TPA	DTW	140	797.0	7.00	72S	7	35000.	.92	17.50
TPA	DTW	990	797.0	7.00	D8S	7	41000.	.90	32.15
TPA	FLL	1185	103.0	18.00	L10	7	26040.	2.16	108.54
TPA	JFK	250	928.0	8.00	72S	7	35000.	1.06	20.00
TPA	JFK	284	928.0	8.00	72S	7	35000.	1.06	20.00
TPA	MIA	287	103.0	18.00	72S	7	26040.	2.29	54.43
TPA	MIA	745	103.0	18.00	D9S	7	28040.	2.36	34.67
TPA	MIA	753	103.0	18.00	D9S	7	28040.	2.36	34.67
TPA	ORD	256	793.0	6.00	72S	7	35000.	.79	15.00
TPA	ORD	282	793.0	6.00	72S	7	35000.	.79	15.00
TPA	ORD	352	793.0	6.00	72S	7	35000.	.79	15.00

ORG A/P DST A/P FLT NO RANGE NMI RNAV BENE A/C F CRUISE ALT TIME BENE FUEL BENE

TABLE G.4
AMERICAN AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
BAL	DFW	371	1006.0	8.00	707	7	41000.	1.02	30.66
BAL	DFW	211	1006.0	8.00	707	7	41000.	1.02	30.66
BAL	DFW	325	1006.0	8.00	727	7	35000.	1.04	18.32
BAL	DFW	371	1006.0	8.00	707	7	41000.	1.02	30.66
BAL	DFW	211	1006.0	8.00	707	7	41000.	1.02	30.66
BAL	DFW	325	1006.0	8.00	727	7	35000.	1.04	18.32
BDL	ORD	333	589.0	-2.00	727	7	35000.	-.26	-4.58
BDL	ORD	193	589.0	-2.00	727	7	35000.	-.26	-4.58
BDL	ORD	153	589.0	-2.00	727	7	35000.	-.26	-4.58
BNA	DCA	274	413.0	17.00	727	7	35000.	2.22	38.92
BNA	DCA	326	413.0	17.00	727	7	35000.	2.22	38.92
BNA	DCA	569	413.0	17.00	727	7	35000.	2.22	38.92
BNA	MEM	323	87.0	0.00	727	7	24760.	0.00	0.00
BNA	MEM	605	87.0	0.00	727	7	24760.	0.00	0.00
BNA	MEM	383	87.0	0.00	727	7	24760.	0.00	0.00
BNA	MEM	35	87.0	0.00	727	6	24760.	0.00	0.00
BOS	BAL	371	243.0	-1.00	707	7	34120.	-.13	-3.51
BOS	BAL	371	243.0	-1.00	707	7	34120.	-.13	-3.51
BOS	DCA	429	244.0	0.00	727	5	34160.	0.00	0.00
BOS	DCA	421	244.0	0.00	727	7	34160.	0.00	0.00
BOS	DCA	275	244.0	0.00	727	7	34160.	0.00	0.00
BOS	DCA	651	244.0	0.00	727	7	34160.	0.00	0.00
BOS	DCA	281	244.0	0.00	727	6	34160.	0.00	0.00
BOS	DCA	305	244.0	0.00	727	7	34160.	0.00	0.00
BOS	DCA	453	244.0	0.00	727	7	34160.	0.00	0.00
BOS	DCA	607	244.0	0.00	727	6	34160.	0.00	0.00
BOS	DFW	439	1316.0	12.00	707	7	41000.	1.53	45.99
BOS	JFK	117	76.0	17.00	707	7	23880.	2.12	70.69
BOS	JFK	95	76.0	17.00	707	7	23880.	2.12	70.69
BOS	LAX	11	2214.0	27.00	D10	7	41000.	3.42	112.63
BOS	ORD	273	660.0	-4.00	707	7	41000.	-.51	-15.33
BOS	ORD	445	660.0	-4.00	707	7	41000.	-.51	-15.33
BOS	ORD	135	660.0	-4.00	707	7	41000.	-.51	-15.33
BOS	ORD	579	660.0	-4.00	727	6	35000.	-.52	-9.16
BOS	ORD	157	660.0	-4.00	D10	7	41000.	-.51	-16.69
BUF	DTW	23	127.0	3.00	707	7	27960.	.37	11.39
BUF	ORD	181	314.0	0.00	D10	7	36960.	0.00	0.00
BUF	ORD	599	314.0	0.00	727	7	35000.	0.00	0.00
BUF	ORD	355	314.0	0.00	727	7	35000.	0.00	0.00
BUF	ORD	131	314.0	0.00	707	7	36960.	0.00	0.00
CLE	DFW	559	839.0	7.00	707	7	41000.	.89	26.82
CLE	LAX	73	1668.0	18.00	707	7	41000.	2.30	68.98
CLE	LAX	79	1668.0	18.00	707	7	41000.	2.30	68.98
CLE	LGA	360	258.0	-7.00	727	7	34720.	-.91	-16.13
CLE	LGA	540	258.0	-7.00	727	7	34720.	-.91	-16.13
CLE	LGA	130	258.0	-7.00	727	7	34720.	-.91	-16.13
CLE	LGA	290	258.0	-7.00	727	6	34720.	-.91	-16.13
CLE	STL	475	345.0	10.00	707	7	37960.	1.28	36.35
CLE	STL	133	345.0	10.00	707	7	37960.	1.28	36.35
CLE	STL	385	345.0	10.00	727	7	35000.	1.30	22.90
CLE	STL	209	345.0	10.00	727	6	35000.	1.30	22.90
CMH	LGA	256	318.0	10.00	727	7	35000.	1.30	22.90
CMH	LGA	612	318.0	10.00	727	7	35000.	1.30	22.90
CMH	LGA	480	318.0	10.00	727	7	35000.	1.30	22.90
DCA	BNA	605	392.0	1.00	727	7	35000.	.13	2.29
DCA	BNA	369	392.0	1.00	727	7	35000.	.13	2.29
DCA	BNA	511	392.0	1.00	727	7	35000.	.13	2.29
DCA	BOS	516	261.0	17.00	727	5	34840.	2.22	39.07
DCA	BOS	232	261.0	17.00	727	7	34840.	2.22	39.07
DCA	BOS	400	261.0	17.00	727	7	34840.	2.22	39.07
DCA	BOS	506	261.0	17.00	727	7	34840.	2.22	39.07
DCA	BOS	350	261.0	17.00	727	7	34840.	2.22	39.07
DCA	BOS	352	261.0	17.00	727	7	34840.	2.22	39.07
DCA	BOS	568	261.0	17.00	727	6	34840.	2.22	39.07
DCA	BOS	398	261.0	17.00	727	6	34840.	2.22	39.07
DCA	LGA	496	66.0	-3.00	727	5	23080.	-.39	-8.79
DCA	LGA	245	66.0	-3.00	727	7	23080.	-.39	-8.79
DCA	LGA	312	66.0	-3.00	727	7	23080.	-.39	-8.79
DCA	LGA	522	66.0	-3.00	727	1	23080.	-.39	-8.79
DCA	LGA	505	66.0	-3.00	727	6	23080.	-.39	-8.79
DCA	LGA	557	66.0	-3.00	727	7	23080.	-.39	-8.79
DCA	LGA	447	66.0	-3.00	727	7	23080.	-.39	-8.79
DCA	LGA	559	66.0	-3.00	727	6	23080.	-.39	-8.79
DCA	LGA	348	66.0	-3.00	727	6	23080.	-.39	-8.79
DCA	MEM	463	568.0	2.00	727	7	35000.	.26	4.58
DCA	MEM	173	568.0	2.00	727	7	35000.	.26	4.58
DCA	ORD	563	455.0	42.00	727	7	35000.	5.48	96.16
DCA	ORD	565	455.0	42.00	727	7	35000.	5.48	96.16
DCA	ORD	427	455.0	42.00	727	7	35000.	5.48	96.16
DCA	ORD	141	455.0	42.00	727	7	35000.	5.48	96.16

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
DCA	ORD	411	455.0	42.00	727	6	35000.	5.48	96.16
DCA	ORD	281	455.0	42.00	727	7	35000.	5.48	96.16
DCA	ORD	137	455.0	42.00	727	7	35000.	5.48	96.16
DCA	ORD	305	455.0	42.00	727	6	35000.	5.48	96.16
DCA	ORD	437	455.0	42.00	727	7	35000.	5.48	96.16
DFW	BAL	262	980.0	17.00	707	7	41000.	2.17	65.15
DFW	BAL	504	980.0	17.00	727	7	35000.	2.22	38.92
DFW	BAL	324	980.0	17.00	707	7	41000.	2.17	65.15
DFW	BAL	262	980.0	17.00	707	7	41000.	2.17	65.15
DFW	BAL	504	980.0	17.00	727	7	35000.	2.22	38.92
DFW	BAL	324	980.0	17.00	707	7	41000.	2.17	65.15
DFW	BNA	274	480.0	22.00	727	7	35000.	2.87	50.37
DFW	BNA	200	430.0	22.00	727	7	35000.	2.87	50.37
DFW	BNA	280	480.0	22.00	727	7	35000.	2.87	50.37
DFW	BNA	270	480.0	22.00	727	6	35000.	2.87	50.37
DFW	CLE	84	835.0	7.00	707	7	41000.	.89	26.82
DFW	CLE	130	835.0	7.00	727	7	35000.	.91	16.03
DFW	ELP	333	396.0	4.00	727	7	35000.	.52	9.16
DFW	ELP	85	396.0	4.00	727	7	35000.	.52	9.16
DFW	ELP	141	396.0	4.00	727	7	35000.	.52	9.16
DFW	ELP	69	396.0	4.00	707	7	39592.	.51	14.96
DFW	ELP	325	396.0	4.00	727	7	35000.	.52	9.16
DFW	IAD	38	955.0	8.00	707	7	41000.	1.02	30.66
DFW	IAD	286	955.0	8.00	707	7	41000.	1.02	30.66
DFW	IAD	378	955.0	8.00	D10	7	41000.	1.01	33.37
DFW	JFK	164	1186.0	10.00	707	7	41000.	1.28	38.32
DFW	JFK	94	1186.0	10.00	D10	7	41000.	1.27	41.72
DFW	LAX	27	999.0	0.00	727	7	35000.	0.00	0.00
DFW	LAX	371	999.0	0.00	707	7	41000.	0.00	0.00
DFW	LAX	605	999.0	0.00	727	7	35000.	0.00	0.00
DFW	LAX	239	999.0	0.00	727	7	35000.	0.00	0.00
DFW	LAX	211	999.0	0.00	707	7	41000.	0.00	0.00
DFW	LAX	439	999.0	0.00	707	7	41000.	0.00	0.00
DFW	LAX	3439	999.0	0.00	727	7	35000.	0.00	0.00
DFW	LAX	317	999.0	0.00	D10	7	41000.	0.00	0.00
DFW	LAX	95	999.0	0.00	707	7	41000.	0.00	0.00
DFW	LAX	2095	999.0	0.00	707	7	41000.	0.00	0.00
DFW	LGA	82	1158.0	47.00	727	7	35000.	6.13	107.61
DFW	LGA	672	1158.0	47.00	727	5	35000.	6.13	107.61
DFW	LGA	98	1158.0	47.00	727	7	35000.	6.13	107.61
DFW	LGA	228	1158.0	47.00	727	6	35000.	6.13	107.61
DFW	LGA	266	1158.0	47.00	727	7	35000.	6.13	107.61
DFW	LIT	376	196.0	18.00	727	7	31987.	2.32	43.77
DFW	LIT	548	196.0	18.00	727	7	31987.	2.32	43.77
DFW	LIT	122	196.0	18.00	727	7	31987.	2.32	43.77
DFW	LIT	177	196.0	18.00	727	7	31987.	2.32	43.77
DFW	MEM	180	304.0	19.00	727	7	35000.	2.48	43.50
DFW	MEM	296	304.0	19.00	727	7	35000.	2.48	43.50
DFW	MEM	398	304.0	19.00	727	7	35000.	2.48	43.50
DFW	MEM	240	304.0	19.00	727	7	35000.	2.48	43.50
DFW	MEM	264	304.0	19.00	727	7	35000.	2.48	43.50
DFW	OKC	572	67.0	-1.00	727	7	23160.	-.13	-2.93
DFW	OKC	340	67.0	-1.00	727	7	23160.	-.13	-2.93
DFW	OKC	460	67.0	-1.00	727	7	23160.	-.13	-2.93
DFW	OKC	306	67.0	-1.00	707	7	23160.	-.13	-4.18
DFW	ORD	210	600.0	5.00	707	7	41000.	.64	19.16
DFW	ORD	30	600.0	5.00	727	7	35000.	.65	11.45
DFW	ORD	332	600.0	5.00	707	7	41000.	.64	19.16
DFW	ORD	442	600.0	5.00	707	1	41000.	.64	19.16
DFW	ORD	590	600.0	5.00	727	6	35000.	.65	11.45
DFW	ORD	316	600.0	5.00	727	7	35000.	.65	11.45
DFW	ORD	310	600.0	5.00	727	6	35000.	.65	11.45
DFW	ORD	402	600.0	5.00	727	7	35000.	.65	11.45
DFW	ORD	158	600.0	5.00	707	6	41000.	.64	19.16
DFW	PHX	159	713.0	5.00	707	7	41000.	.64	19.16
DFW	PHX	229	713.0	5.00	727	7	35000.	.65	11.45
DFW	SAT	297	127.0	8.00	707	7	27960.	.99	30.37
DFW	SFO	203	1177.0	0.00	727	6	35000.	0.00	0.00
DFW	SFO	487	1177.0	0.00	707	7	41000.	0.00	0.00
DFW	SFO	603	1177.0	0.00	727	7	35000.	0.00	0.00
DFW	SFO	42	1177.0	0.00	D10	7	41000.	0.00	0.00
DFW	SFO	173	1177.0	0.00	727	7	35000.	0.00	0.00
DFW	SFO	267	1177.0	0.00	707	7	41000.	0.00	0.00
DFW	STL	358	400.0	9.00	727	7	35000.	1.17	20.61
DFW	STL	560	400.0	9.00	707	7	34720.	1.15	33.74
DFW	STL	546	400.0	9.00	727	7	35000.	1.17	20.61
DTW	BOS	218	469.0	0.00	727	7	35000.	0.00	0.00
DTW	BOS	242	469.0	0.00	707	7	41000.	0.00	0.00
DTW	BOS	374	469.0	0.00	727	7	35000.	0.00	0.00
DTW	BOS	406	469.0	0.00	707	7	41000.	0.00	0.00

TABLE G.4
AMERICAN AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
DTW	BUF	92	163.0	44.00	707	7	30227.	5.47	160.29
DTW	BUF	604	163.0	44.00	707	7	30227.	5.47	160.29
DTW	LAX	67	1663.0	12.00	707	7	41000.	1.53	45.99
DTW	LAX	41	1663.0	12.00	D10	7	41000.	1.52	50.06
DTW	LGA	124	351.0	4.00	727	5	35000.	.52	9.16
DTW	LGA	380	351.0	4.00	727	7	35000.	.52	9.16
DTW	LGA	512	351.0	4.00	727	7	35000.	.52	9.16
DTW	LGA	574	351.0	4.00	727	7	35000.	.52	9.16
DTW	LGA	436	351.0	4.00	727	7	35000.	.52	9.16
DTW	LGA	530	351.0	4.00	727	7	35000.	.52	9.16
DTW	LGA	552	351.0	4.00	727	6	35000.	.52	9.16
DTW	LGA	473	351.0	4.00	727	6	35000.	.52	9.16
DTW	LGA	618	351.0	4.00	727	7	35000.	.52	9.16
DTW	LGA	650	351.0	4.00	727	7	35000.	.52	9.16
DTW	LGA	476	351.0	4.00	727	6	35000.	.52	9.16
DTW	ORD	107	101.0	-4.00	D10	7	25880.	-.49	-22.59
DTW	ORD	169	101.0	-4.00	D10	7	25880.	-.49	-22.59
DTW	ORD	415	101.0	-4.00	707	7	25880.	-.49	-16.05
DTW	ORD	105	101.0	-4.00	707	7	25880.	-.49	-16.05
DTW	ORD	505	101.0	-4.00	727	7	25880.	-.50	-11.13
DTW	ORD	553	101.0	-4.00	707	7	25880.	-.49	-16.05
DTW	ORD	591	101.0	-4.00	727	6	25880.	-.50	-11.13
DTW	ORD	435	101.0	-4.00	727	7	25880.	-.50	-11.13
DTW	SFO	23	1736.0	18.00	707	7	41000.	2.30	68.98
DTW	SFO	91	1736.0	18.00	707	7	41000.	2.30	68.98
ELP	LAX	427	508.0	0.00	727	7	35000.	0.00	0.00
ELP	SAT	532	342.0	0.00	727	7	35000.	0.00	0.00
ELP	TUS	71	145.0	0.00	727	7	29267.	0.00	0.00
ELP	TUS	69	145.0	0.00	707	7	29267.	0.00	0.00
ELP	TUS	325	145.0	0.00	727	7	29267.	0.00	0.00
EWR	IAD	317	60.0	0.00	D10	7	22200.	0.00	0.00
EWR	LAX	9	2034.0	0.00	707	7	41000.	0.00	0.00
EWR	ORD	449	531.0	17.00	707	7	41000.	2.17	65.15
EWR	ORD	213	531.0	17.00	D10	7	41000.	2.15	70.92
EWR	ORD	581	531.0	17.00	707	7	41000.	2.17	65.15
EWR	ORD	47	531.0	17.00	707	7	41000.	2.17	65.15
IAD	BOS	112	264.0	19.00	707	7	34960.	2.41	67.01
IAD	BOS	620	264.0	19.00	727	7	34960.	2.48	43.54
IAD	EWR	378	99.0	-3.00	D10	7	25720.	-.37	-16.98
IAD	EWR	110	99.0	-3.00	707	7	25720.	-.37	-12.10
IAD	JFK	114	100.0	-1.00	707	7	25800.	-.12	-4.02
IAD	LAX	77	1947.0	22.00	707	7	41000.	2.81	84.31
JFK	BOS	10	106.0	50.00	D10	7	26280.	6.12	280.83
JFK	BOS	118	106.0	50.00	707	7	26280.	6.13	198.11
JFK	BOS	4	106.0	50.00	707	6	26280.	6.13	198.11
JFK	DFW	81	1127.0	10.00	707	7	41000.	1.28	38.32
JFK	DFW	95	1127.0	10.00	707	7	41000.	1.28	38.32
JFK	IAD	55	104.0	3.00	707	7	26120.	.37	11.95
JFK	LAX	1	2040.0	0.00	707	7	41000.	0.00	0.00
JFK	LAX	3	2040.0	0.00	747	7	37000.	0.00	0.00
JFK	LAX	5	2040.0	0.00	707	6	41000.	0.00	0.00
JFK	LAX	21	2040.0	0.00	D10	7	41000.	0.00	0.00
JFK	PHX	117	1781.0	19.00	707	7	41000.	2.43	72.81
JFK	PHX	187	1781.0	19.00	707	7	41000.	2.43	72.81
JFK	PHX	49	1781.0	19.00	D10	7	41000.	2.41	79.26
JFK	SAN	155	2041.0	24.00	707	7	41000.	3.07	91.97
JFK	SFO	59	2165.0	26.00	707	7	41000.	3.32	99.63
JFK	SFO	17	2165.0	26.00	D10	7	41000.	3.29	108.46
JFK	SFO	19	2165.0	26.00	D10	7	41000.	3.29	108.46
JFK	STL	151	681.0	5.00	707	1	41000.	.64	19.16
JFK	STL	37	681.0	5.00	D10	7	41000.	.63	20.86
LAX	BOS	12	2180.0	26.00	D10	7	41000.	3.29	108.46
LAX	CLE	74	1684.0	18.00	707	7	41000.	2.30	68.98
LAX	CLE	72	1684.0	18.00	707	7	41000.	2.30	68.98
LAX	DFW	200	991.0	9.00	727	7	35000.	1.17	20.61
LAX	DFW	122	991.0	9.00	727	7	35000.	1.17	20.61
LAX	DFW	324	991.0	9.00	707	7	41000.	1.15	34.49
LAX	DFW	158	991.0	9.00	707	7	41000.	1.15	34.49
LAX	DFW	306	991.0	9.00	707	7	41000.	1.15	34.49
LAX	DFW	314	991.0	9.00	707	7	41000.	1.15	34.49
LAX	DFW	378	991.0	9.00	D10	7	41000.	1.14	37.54
LAX	DFW	262	991.0	9.00	707	7	41000.	1.15	34.49
LAX	DFW	330	991.0	9.00	707	7	41000.	1.15	34.49
LAX	DTW	68	1619.0	15.00	707	7	41000.	1.92	57.48
LAX	DTW	96	1619.0	15.00	D10	7	41000.	1.90	62.57
LAX	ELP	532	513.0	0.00	727	7	35000.	0.00	0.00
LAX	EWR	8	2032.0	24.00	707	6	41000.	3.07	91.97
LAX	IAD	76	1913.0	24.00	D10	7	41000.	3.04	100.12
LAX	IAD	110	1913.0	24.00	707	7	41000.	3.07	91.97
LAX	JFK	2	2032.0	-16.00	D10	7	41000.	-2.03	-66.75
LAX	JFK	32	2032.0	-16.00	747	7	37000.	-2.00	-110.30
LAX	JFK	4	2032.0	-16.00	707	6	41000.	-2.05	-61.31
LAX	JFK	10	2032.0	-16.00	D10	7	41000.	-2.03	-66.75
LAX	OKC	382	936.0	7.00	727	7	35000.	.91	16.03
LAX	OKC	178	936.0	7.00	707	7	41000.	.89	26.82
LAX	ORD	184	1412.0	14.00	D10	7	41000.	1.77	58.40
LAX	ORD	194	1412.0	14.00	D10	7	41000.	1.77	58.40
LAX	ORD	202	1412.0	14.00	707	7	41000.	1.79	53.65
LAX	ORD	218	1412.0	14.00	727	7	35000.	1.83	32.05
LAX	ORD	196	1412.0	14.00	707	7	41000.	1.79	53.65
LAX	ORD	2218	1412.0	14.00	727	7	35000.	1.83	32.05
LAX	PHL	60	1995.0	14.00	707	7	41000.	1.79	53.65
LAX	PHX	630	208.0	0.00	D10	7	32627.	0.00	0.00
LAX	PHX	54	208.0	0.00	707	7	32627.	0.00	0.00
LAX	PHX	422	208.0	0.00	727	7	32627.	0.00	0.00
LAX	PHX	38	208.0	0.00	D10	7	32627.	0.00	0.00
LAX	STL	526	1304.0	12.00	727	7	35000.	1.57	27.47
LAX	STL	390	1304.0	12.00	727	7	35000.	1.57	27.47
LAX	STL	412	1304.0	12.00	707	7	41000.	1.53	45.99
LAX	TUS	288	288.0	0.00	707	6	35920.	0.00	0.00
LGA	BUF	529	146.0	-3.00	727	7	29320.	-.38	-7.58
LGA	BUF	599	146.0	-3.00	727	6	29320.	-.38	-7.58
LGA	BUF	355	146.0	-3.00	727	7	29320.	-.38	-7.58
LGA	BUF	105	146.0	-3.00	727	7	29320.	-.38	-7.58
LGA	BUF	531	146.0	-3.00	727	7	29320.	-.38	-7.58
LGA	BUF	419	146.0	-3.00	727	6	29320.	-.39	-7.58
LGA	CLE	363	270.0	10.00	727	6	35000.	1.30	22.90
LGA	CLE	239	270.0	10.00	727	7	35000.	1.30	22.90
LGA	CLE	209	270.0	10.00	727	6	35000.	1.30	22.90
LGA	CLE	35	270.0	10.00	727	7	35000.	1.30	22.90
LGA	DAY	177	385.0	13.00	727	7	35000.	1.70	29.76
LGA	DCA	417	105.0	4.00	727	5	26200.	.50	11.02
LGA	DCA	440	105.0	4.00	727	7	26200.	.50	11.02
LGA	DCA	463	105.0	4.00	727	7	26200.	.50	11.02
LGA	DCA	369	105.0	4.00	727	7	26200.	.50	11.02
LGA	DCA	294	105.0	4.00	727	7	26200.	.50	11.02
LGA	DCA	173	105.0	4.00	727	7	26200.	.50	11.02
LGA	DCA	511	105.0	4.00	727	7	26200.	.50	11.02
LGA	DCA	430	105.0	4.00	727	6	26200.	.50	11.02
LGA	DTW	539	338.0	1.00	727	5	35000.	.13	2.29
LGA	DTW	519	338.0	1.00	727	7	35000.	.13	2.29
LGA	DTW	593	338.0	1.00	727	7	35000.	.13	2.29
LGA	DTW	379	338.0	1.00	727	7	35000.	.13	2.29
LGA	DTW	521	338.0	1.00	727	7	35000.	.13	2.29
LGA	DTW	505	338.0	1.00	727	6	35000.	.13	2.29
LGA	DTW	497	338.0	1.00	727	7	35000.	.13	2.29
LGA	DTW	591	338.0	1.00	727	6	35000.	.13	2.29
LGA	DTW	595	338.0	1.00	727	7	35000.	.13	2.29
LGA	DTW	455	338.0	1.00	727	6	35000.	.13	2.29
LGA	DTW	447	338.0	1.00	727	7	35000.	.13	2.29
LGA	ORD	201	532.0	15.00	727	5	35000.	1.96	34.34
LGA	ORD	609	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ORD	235	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ORD	303	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ORD	433	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ORD	221	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ORD	493	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ORD	633	532.0	15.00	727	6	35000.	1.96	34.34
LGA	ORD	431	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ORD	315	532.0	15.00	727	6	35000.	1.96	34.34
LGA	ORD	391	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ORD	377	532.0	15.00	727	6	35000.	1.96	34.34
LGA	ORD	259	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ROC	537	121.0	7.00	727	6	27480.	.88	18.55
LGA	ROC	667	121.0	7.00	727	6	27480.	.88	18.55
LGA	ROC	337	121.0	7.00	727	7	27480.	.88	18.55
LGA	ROC	301	121.0	7.00	727	7	27480.	.88	18.55
LGA	ROC	403	121.0	7.00	727	7	27480.	.88	18.55
LGA	SDF	247	483.0	15.00	727	7	35000.	1.96	34.34
LGA	SDF	299	483.0	15.00	727	6	35000.	1.96	34.34
LGA	STL	233	675.0	5.00	727	7	35000.	.65	11.45
LGA	STL	473	675.0	5.00	727	7	35000.	.65	11.45
MEM	BNA	606	87.0	3.00	727	7	24760.	.38	8.60
MEM	BNA	528	87.0	3.00	707	7	24760.	.37	12.39
MEM	BNA	264	87.0	3.00	727	1	24760.	.38	8.60
MEM	DCA	296	597.0	35.00	727	7	35000.	4.57	80.13
MEM	DCA	398	597.0	35.00	727	6	35000.	4.57	80.13
MEM	DFW	495	295.0	9.00	727	7	35000.	1.17	20.61
MEM	DFW	605	295.0	9.00	727	7	35000.	1.17	20.61
MEM	DFW	283	295.0	9.00	727	7	35000.	1.17	20.61

TABLE G.4
AMERICAN AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
MEM	DFW	173	295.0	9.00	727	7	35000.	1.17	20.61
MEM	LAX	323	1379.0	13.00	727	7	35000.	1.70	29.76
MEM	LAX	383	1379.0	13.00	727	7	35000.	1.70	29.76
MEM	LGA	488	757.0	6.00	727	7	35000.	.76	13.74
MEM	LGA	122	757.0	6.00	727	7	35000.	.78	13.74
OKC	LAX	147	925.0	-3.00	707	7	41000.	-.38	-11.50
OKC	LAX	119	925.0	-3.00	727	7	35000.	-.39	-6.87
ORD	BDL	544	598.0	18.00	707	7	41000.	2.30	68.98
ORD	BDL	310	598.0	18.00	727	7	35000.	2.35	41.21
ORD	BDL	222	598.0	18.00	707	7	41000.	2.30	68.98
ORD	BOS	210	656.0	-15.00	707	7	41000.	-1.92	-57.48
ORD	BOS	300	656.0	-15.00	707	7	41000.	-1.92	-57.48
ORD	BOS	220	656.0	-15.00	707	7	41000.	-1.92	-57.48
ORD	BOS	28	656.0	-15.00	707	6	41000.	-1.92	-57.48
ORD	BOS	404	656.0	-15.00	707	7	41000.	-1.92	-57.48
ORD	BUF	254	349.0	39.00	727	7	35000.	5.09	89.29
ORD	BUF	558	349.0	39.00	727	7	35000.	5.09	89.29
ORD	BUF	316	349.0	39.00	727	7	35000.	5.09	89.29
ORD	BUF	194	349.0	39.00	D10	7	38088.	4.94	177.44
ORD	DCA	312	444.0	25.00	727	7	35000.	3.26	57.24
ORD	DCA	572	444.0	25.00	727	7	35000.	3.26	57.24
ORD	DCA	116	444.0	25.00	727	7	35000.	3.26	57.24
ORD	DCA	590	444.0	25.00	727	7	35000.	3.26	57.24
ORD	DCA	352	444.0	25.00	727	7	35000.	3.26	57.24
ORD	DCA	638	444.0	25.00	727	6	35000.	3.26	57.24
ORD	DCA	340	444.0	25.00	727	7	35000.	3.26	57.24
ORD	DCA	490	444.0	25.00	727	6	35000.	3.26	57.24
ORD	DCA	334	444.0	25.00	727	7	35000.	3.26	57.24
ORD	DFW	333	622.0	19.00	727	7	35000.	2.48	43.50
ORD	DFW	415	622.0	19.00	707	7	41000.	2.43	72.81
ORD	DFW	599	622.0	19.00	727	7	35000.	2.48	43.50
ORD	DFW	141	622.0	19.00	727	7	35000.	2.48	43.50
ORD	DFW	633	622.0	19.00	727	6	35000.	2.48	43.50
ORD	DFW	431	622.0	19.00	727	7	35000.	2.48	43.50
ORD	DFW	301	622.0	19.00	727	7	35000.	2.48	43.50
ORD	DFW	627	622.0	19.00	727	6	35000.	2.48	43.50
ORD	DFW	611	622.0	19.00	707	6	41000.	2.43	72.81
ORD	DTW	372	103.0	1.00	707	7	26040.	.12	3.99
ORD	DTW	374	103.0	1.00	727	7	26040.	.13	2.77
ORD	DTW	284	103.0	1.00	727	7	26040.	.13	2.77
ORD	DTW	630	103.0	1.00	D10	7	26040.	.12	5.64
ORD	DTW	650	103.0	1.00	727	7	26040.	.13	2.77
ORD	DTW	104	103.0	1.00	D10	7	26040.	.12	5.64
ORD	DTW	54	103.0	1.00	707	7	26040.	.12	3.99
ORD	DTW	202	103.0	1.00	707	7	26040.	.12	3.99
ORD	DTW	218	103.0	1.00	727	7	26040.	.13	2.77
ORD	EWR	196	516.0	-3.00	707	7	41000.	-.38	-11.50
ORD	EWR	418	516.0	-3.00	707	7	41000.	-.38	-11.50
ORD	EWR	182	516.0	-3.00	D10	7	41000.	-.38	-12.51
ORD	EWR	234	516.0	-3.00	727	6	35000.	-.39	-6.87
ORD	LAX	181	1409.0	10.00	D10	7	41000.	1.27	41.72
ORD	LAX	197	1409.0	10.00	D10	7	41000.	1.27	41.72
ORD	LAX	185	1409.0	10.00	D10	7	41000.	1.27	41.72
ORD	LAX	131	1409.0	10.00	707	7	41000.	1.28	38.32
ORD	LAX	435	1409.0	10.00	727	7	35000.	1.30	22.90
ORD	LGA	236	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	492	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	302	519.0	1.00	727	5	35000.	.13	2.29
ORD	LGA	446	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	358	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	208	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	304	519.0	1.00	727	6	35000.	.13	2.29
ORD	LGA	338	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	466	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	168	519.0	1.00	727	6	35000.	.13	2.29
ORD	LGA	154	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	344	519.0	1.00	727	6	35000.	.13	2.29
ORD	LGA	268	519.0	1.00	727	7	35000.	.13	2.29
ORD	PHX	107	1204.0	11.00	D10	7	41000.	1.39	45.89
ORD	PHX	291	1204.0	11.00	D10	7	41000.	1.39	45.89
ORD	PHX	617	1204.0	11.00	727	7	35000.	1.43	25.19
ORD	PHX	157	1204.0	11.00	D10	7	41000.	1.39	45.89
ORD	ROC	368	386.0	23.00	727	7	35000.	3.00	52.66
ORD	ROC	482	386.0	23.00	707	7	39272.	2.94	65.56
ORD	ROC	26	386.0	23.00	727	7	35000.	3.00	52.66
ORD	ROC	402	386.0	23.00	727	7	35000.	3.00	52.66
ORD	SAN	277	1400.0	3.00	727	7	35000.	.39	6.87
ORD	SAN	445	1400.0	3.00	707	7	41000.	.38	11.50
ORD	SAN	381	1400.0	3.00	727	7	35000.	.39	6.87
ORD	SAN	2381	1400.0	3.00	707	7	41000.	.38	11.50

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
ORD	SFO	265	1513.0	16.00	D10	7	41000.	2.03	66.75
ORD	SFO	213	1513.0	16.00	D10	7	41000.	2.03	66.75
ORD	SFO	205	1513.0	16.00	707	7	41000.	2.05	61.31
ORD	SFO	47	1513.0	16.00	707	6	41000.	2.05	61.31
ORD	SLC	563	1007.0	9.00	727	7	35000.	1.17	20.61
ORD	SLC	303	1007.0	9.00	727	7	35000.	1.17	20.61
ORD	SLC	137	1007.0	9.00	727	7	35000.	1.17	20.61
ORD	STL	609	136.0	12.00	727	7	28680.	1.52	30.75
ORD	STL	493	136.0	12.00	727	7	28680.	1.52	30.75
ORD	TUL	483	440.0	28.00	727	7	35000.	3.65	64.11
ORD	TUL	119	440.0	28.00	727	7	35000.	3.65	64.11
ORD	TUL	315	440.0	28.00	727	7	35000.	3.65	64.11
ORD	TUL	437	440.0	28.00	727	7	35000.	3.65	64.11
ORD	TUS	201	1175.0	11.00	727	7	35000.	1.43	25.19
ORD	TUS	221	1175.0	11.00	727	7	35000.	1.43	25.19
ORD	TUS	581	1175.0	11.00	707	7	41000.	1.41	42.15
ORD	TUS	481	1175.0	11.00	727	7	35000.	1.43	25.19
PHL	LAX	63	2026.0	23.00	707	7	41000.	2.94	88.14
PHX	DFW	618	716.0	5.00	727	7	35000.	.65	11.45
PHX	DFW	498	716.0	5.00	707	7	41000.	.64	19.16
PHX	DFW	622	716.0	5.00	727	7	35000.	.65	11.45
PHX	DFW	346	716.0	5.00	727	7	35000.	.65	11.45
PHX	DFW	2346	716.0	5.00	727	7	35000.	.65	11.45
PHX	JFK	186	1799.0	17.00	707	7	41000.	2.17	65.15
PHX	JFK	118	1799.0	17.00	707	7	41000.	2.17	65.15
PHX	JFK	38	1799.0	17.00	D10	7	41000.	2.15	70.92
PHX	LAX	533	208.0	3.00	707	7	32627.	.38	10.51
PHX	LAX	291	208.0	3.00	D10	7	32627.	.37	14.73
PHX	LAX	283	208.0	3.00	727	7	32627.	.39	7.23
PHX	ORD	630	1163.0	11.00	D10	7	41000.	1.39	45.89
PHX	ORD	66	1163.0	11.00	D10	7	41000.	1.39	45.89
PHX	ORD	54	1163.0	11.00	707	7	41000.	1.41	42.15
PHX	ORD	246	1163.0	11.00	D10	7	41000.	1.39	45.89
PHX	SAN	465	192.0	0.00	707	7	31773.	0.00	0.00
PHX	STL	366	1012.0	2.00	727	7	35000.	.26	4.58
PHX	STL	134	1012.0	2.00	727	7	35000.	.26	4.58
ROC	LGA	384	116.0	0.00	727	5	27080.	0.00	0.00
ROC	LGA	450	116.0	0.00	727	7	27080.	0.00	0.00
ROC	LGA	538	116.0	0.00	727	7	27080.	0.00	0.00
ROC	LGA	26	116.0	0.00	727	7	27080.	0.00	0.00
ROC	ORD	367	366.0	3.00	727	7	35000.	.39	6.87
ROC	ORD	667	366.0	3.00	727	7	35000.	.39	6.87
ROC	ORD	301	366.0	3.00	727	7	35000.	.39	6.87
SAN	JFK	126	-0.0	0.00	707	7	12600.	0.00	0.00
SAN	ORD	284	1440.0	15.00	727	7	35000.	1.96	34.34
SAN	ORD	28	1440.0	15.00	707	7	41000.	1.92	57.48
SAN	ORD	268	1440.0	15.00	727	7	35000.	1.96	34.34
SAN	PHX	464	192.0	0.00	707	7	31773.	0.00	0.00
SAT	DFW	554	125.0	3.00	707	7	27800.	.37	11.43
SAT	ELP	427	348.0	5.00	727	7	35000.	.65	11.45
SJF	LGA	298	508.0	24.00	727	7	35000.	3.13	54.95
SDF	LGA	250	508.0	24.00	727	6	35000.	3.13	54.95
SDF	MEM	247	206.0	17.00	727	7	32520.	2.19	41.02
SFO	DFW	296	1207.0	12.00	727	7	35000.	1.57	27.47
SFO	DFW	140	1207.0	12.00	D10	7	41000.	1.52	50.06
SFO	DFW	264	1207.0	12.00	727	7	35000.	1.57	27.47
SFO	DFW	94	1207.0	12.00	D10	7	41000.	1.52	50.06
SFO	DFW	84	1207.0	12.00	707	7	41000.	1.53	45.99
SFO	DFW	2084	1207.0	12.00	727	7	35000.	1.57	27.47
SFO	JFK	14	2129.0	26.00	D10	7	41000.	3.29	108.46
SFO	JFK	16	2129.0	26.00	D10	7	41000.	3.29	108.46
SFO	JFK	56	2129.0	26.00	707	6	41000.	3.32	99.63
SFO	ORD	220	1498.0	16.00	707	7	41000.	2.05	61.31
SFO	ORD	182	1498.0	16.00	D10	7	41000.	2.03	66.75
SFO	ORD	214	1498.0	16.00	D10	7	41000.	2.03	66.75
SFO	PHX	366	490.0	32.00	727	7	35000.	4.17	73.27
SFO	PHX	134	490.0	32.00	727	7	35000.	4.17	73.27
SFO	PHX	486	490.0	32.00	727	7	35000.	4.17	73.27
SFO	PHX	246	490.0	32.00	D10	7	41000.	4.05	133.49
SLC	ORD	208	991.0	5.00	727	7	35000.	.65	11.45
SLC	ORD	638	991.0	5.00	727	7	35000.	.65	11.45
SLC	ORD	334	991.0	5.00	727	6	35000.	.65	11.45
SLC	ORD	686	991.0	5.00	727	1	35000.	.65	11.45
STL	CLE	412	358.0	20.00	707	7	38376.	2.56	73.24
STL	CLE	366	358.0	20.00	727	7	35000.	2.61	45.79
STL	CLE	134	358.0	20.00	727	7	35000.	2.61	45.79
STL	DFW	475	399.0	1.00	707	7	39688.	.13	3.75
STL	DFW	297	399.0	1.00	707	7	39688.	.13	3.75
STL	DFW	349	399.0	1.00	727	7	35000.	.13	2.29
STL	DFW	491	399.0	1.00	727	7	35000.	.13	2.29

TABLE G.4
AMERICAN AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
STL	JFK	152	703.0	13.00	707	1	41000.	1.66	49.82
STL	LAX	241	1273.0	7.00	727	7	35000.	.91	16.03
STL	LAX	353	1273.0	7.00	707	7	41000.	.89	26.82
STL	LAX	37	1273.0	7.00	D10	7	41000.	.89	29.20
STL	LGA	106	692.0	2.00	727	7	35000.	.26	4.58
STL	LGA	598	692.0	2.00	727	6	35000.	.26	4.58
STL	ORD	358	120.0	-2.00	727	7	27400.	-.25	-5.31
STL	ORD	26	120.0	-2.00	727	7	27400.	-.25	-5.31
STL	ORD	602	120.0	-2.00	727	7	27400.	-.25	-5.31
STL	PHX	133	1010.0	2.00	707	7	41000.	.26	7.66
STL	PHX	385	1010.0	2.00	727	7	35000.	.26	4.58
STL	TUL	233	217.0	0.00	727	7	33080.	0.00	0.00
STL	TUL	473	217.0	0.00	727	7	33090.	0.00	0.00
SYR	DTW	67	241.0	3.00	707	7	34040.	.38	10.52
SYR	ORD	277	432.0	3.00	727	7	35000.	.39	6.87
SYR	ORD	197	432.0	3.00	D10	7	40744.	.38	12.61
SYR	ORD	503	432.0	3.00	727	7	35000.	.39	6.87
TUL	DFW	672	122.0	0.00	727	7	27560.	0.00	0.00
TUL	DFW	467	122.0	0.00	707	7	27560.	0.00	0.00
TUL	ORD	446	418.0	10.00	727	7	35000.	1.30	22.90
TUL	ORD	338	418.0	10.00	727	7	35000.	1.30	22.90
TUL	ORD	490	418.0	10.00	727	7	35000.	1.30	22.90
TUL	ORD	178	418.0	10.00	707	7	40296.	1.28	37.86
TUL	STL	346	218.0	2.00	727	7	33120.	.26	4.78
TUL	STL	484	218.0	2.00	707	7	33120.	.25	6.97
TUS	ELP	336	149.0	5.00	707	7	29480.	.62	18.43
TUS	ELP	288	149.0	5.00	707	7	29480.	.62	18.43
TUS	ORD	418	1378.0	11.00	707	7	41000.	1.41	42.15
TUS	ORD	388	1378.0	11.00	727	7	35000.	1.43	25.19
TUS	ORD	650	1378.0	11.00	727	7	35000.	1.43	25.19
TUS	ORD	236	1378.0	11.00	727	7	35000.	1.43	25.19

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE

TABLE G.5
UNITED AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
ABE	PIT	765	140.0	5.00	727	7	29000.	.64	12.69
ABE	PIT	935	140.0	5.00	727	7	29000.	.64	12.69
ATL	BUF	478	535.0	4.00	737	7	35000.	.56	6.30
ATL	BUF	836	535.0	4.00	727	6	35000.	.52	9.16
ATL	BUF	836	535.0	4.00	727	1	35000.	.52	9.16
ATL	CLE	396	414.0	19.00	72S	7	35000.	2.51	47.50
ATL	CLE	432	414.0	19.00	727	7	35000.	2.48	43.50
ATL	CLE	476	414.0	19.00	72S	7	35000.	2.51	47.50
ATL	CLE	888	414.0	19.00	72S	7	35000.	2.51	47.50
ATL	CLE	1112	414.0	19.00	727	7	35000.	2.48	43.50
ATL	JAX	269	146.0	-6.00	72S	7	29320.	-.77	-16.56
ATL	LGA	368	567.0	4.00	727	7	35000.	.52	9.16
ATL	MIA	575	470.0	41.00	727	7	35000.	5.35	93.87
ATL	PBI	491	389.0	-39.00	727	7	35000.	-5.09	-89.29
ATL	PBI	763	389.0	-39.00	737	6	34490.	-5.43	-61.99
ATL	PBI	763	389.0	-39.00	737	1	34490.	-5.43	-61.99
ATL	PIT	384	376.0	5.00	737	7	34360.	.70	7.97
ATL	PIT	440	376.0	5.00	727	6	35000.	.65	11.45
ATL	PIT	440	376.0	5.00	727	1	35000.	.65	11.45
ATL	PIT	470	376.0	5.00	727	7	35000.	.65	11.45
ATL	PIT	672	376.0	5.00	737	7	34360.	.70	7.97
ATL	TPA	473	277.0	11.00	737	7	33370.	1.52	17.83
ATL	TPA	475	277.0	11.00	D10	7	35480.	1.38	52.39
BAL	CLE	697	188.0	26.00	727	7	31560.	3.34	63.62
BAL	CLE	717	188.0	26.00	DC8	7	31560.	3.28	101.66
BAL	DTW	87	266.0	19.00	727	7	35000.	2.48	43.50
BAL	DTW	805	266.0	19.00	727	7	35000.	2.48	43.50
BAL	LAX	63	1924.0	21.00	DC8	7	41000.	2.70	88.23
BAL	ORD	171	436.0	22.00	727	7	35000.	2.87	50.37
BAL	ORD	307	436.0	22.00	DC8	7	40872.	2.83	92.23
BAL	ORD	741	436.0	22.00	727	7	35000.	2.87	50.37
BAL	ORD	793	436.0	22.00	727	7	35000.	2.87	50.37
BAL	ORD	821	436.0	22.00	727	7	35000.	2.87	50.37
BDL	ORD	103	589.0	-2.00	D10	7	41000.	-.25	-8.34
BDL	ORD	121	589.0	-2.00	D8S	6	41000.	-.26	-9.18
BDL	ORD	135	589.0	-2.00	D8S	7	41000.	-.26	-9.18
BDL	ORD	343	589.0	-2.00	727	2	35000.	-.26	-4.58
BDL	ORD	343	589.0	-2.00	727	5	35000.	-.26	-4.58
BDL	ORD	789	589.0	-2.00	D8S	7	41000.	-.26	-9.18
BOI	PDX	587	216.0	7.00	72S	7	33040.	.92	18.30
BOI	PDX	761	216.0	7.00	727	7	33040.	.91	16.75
BOI	SLC	248	164.0	0.00	DC8	7	30280.	0.00	0.00
BOI	SLC	278	164.0	0.00	727	7	30280.	0.00	0.00
BOI	SLC	374	164.0	0.00	DC8	7	30280.	0.00	0.00
BOI	SLC	868	164.0	0.00	727	7	30280.	0.00	0.00
BOS	CLE	301	418.0	16.00	DC8	7	40296.	2.06	66.42
BOS	CLE	317	418.0	16.00	727	7	35000.	2.09	36.63
BOS	CLE	769	418.0	16.00	737	7	34780.	2.23	25.30
BOS	CLE	999	418.0	16.00	727	7	35000.	2.09	36.63
BOS	ORD	121	660.0	-4.00	D8S	1	41000.	-.51	-18.37
BOS	ORD	141	660.0	-4.00	DC8	7	41000.	-.51	-16.81
BOS	ORD	223	660.0	-4.00	DC8	7	41000.	-.51	-16.81
BOS	ORD	237	660.0	-4.00	D10	7	41000.	-.51	-16.69
BOS	ORD	471	660.0	-4.00	D8S	7	41000.	-.51	-18.37
BOS	ORD	489	660.0	-4.00	DC8	7	41000.	-.51	-16.81
BOS	SFO	95	2299.0	28.00	D8S	7	41000.	3.58	128.59
BUF	ATL	473	551.0	4.00	737	7	35000.	.56	6.30
BUF	ATL	833	551.0	4.00	727	6	35000.	.52	9.16
BUF	ATL	833	551.0	4.00	727	1	35000.	.52	9.16
BUF	ORD	139	314.0	0.00	737	7	33740.	0.00	0.00
BUF	ORD	659	314.0	0.00	737	7	33740.	0.00	0.00
BUF	ORD	831	314.0	0.00	72S	7	35000.	0.00	0.00
BUF	PHL	620	191.0	38.00	727	7	31720.	4.89	92.77
CAK	ORD	219	226.0	49.00	737	7	32627.	6.76	80.56
CAK	ORD	481	226.0	49.00	727	1	33440.	6.35	116.24
CAK	ORD	651	226.0	49.00	737	7	32627.	6.76	80.56
CAK	ORD	817	226.0	49.00	737	7	32627.	6.76	80.56
CLE	ATL	269	414.0	22.00	72S	7	35000.	2.90	55.00
CLE	ATL	407	414.0	22.00	727	7	35000.	2.87	50.37
CLE	ATL	475	414.0	22.00	D10	7	40168.	2.78	94.15
CLE	ATL	623	414.0	22.00	737	7	34740.	3.06	34.81
CLE	ATL	941	414.0	22.00	727	7	35000.	2.87	50.37
CLE	ATL	1111	414.0	22.00	727	7	35000.	2.87	50.37
CLE	BAL	714	168.0	1.00	DC8	7	30493.	.13	3.98
CLE	BAL	966	168.0	1.00	727	7	30493.	.13	2.49
CLE	BDL	740	348.0	10.00	727	7	35000.	1.30	22.90
CLE	BDL	852	348.0	10.00	727	7	35000.	1.30	22.90
CLE	BOS	306	404.0	-1.00	727	7	35000.	-.13	-2.29
CLE	BOS	438	404.0	-1.00	727	7	35000.	-.13	-2.29
CLE	BOS	584	404.0	-1.00	727	7	35000.	-.13	-2.29

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
CLE	BOS	732	404.0	-1.00	737	7	34640.	-.14	-1.59
CLE	DCA	642	202.0	35.00	737	7	31987.	4.82	58.29
CLE	DCA	666	202.0	35.00	737	6	31987.	4.82	58.29
CLE	DCA	666	202.0	35.00	737	1	31987.	4.82	58.29
CLE	DCA	722	202.0	35.00	737	7	31987.	4.82	58.29
CLE	DCA	908	202.0	35.00	737	7	31987.	4.82	58.29
CLE	EWR	72	259.0	2.00	DC8	7	34760.	.26	7.72
CLE	EWR	434	259.0	2.00	727	7	34760.	.26	4.60
CLE	EWR	572	259.0	2.00	727	7	34760.	.26	4.60
CLE	EWR	664	259.0	2.00	DC8	7	34760.	.26	7.72
CLE	EWR	734	259.0	2.00	737	7	33190.	.28	3.25
CLE	EWR	856	259.0	2.00	72S	7	34760.	.26	5.03
CLE	EWR	1154	259.0	2.00	72S	7	34760.	.26	5.03
CLE	JFK	182	267.0	9.00	D10	7	35080.	1.13	43.03
CLE	JFK	422	267.0	9.00	737	7	33270.	1.25	14.62
CLE	JFK	804	267.0	9.00	737	7	33270.	1.25	14.62
CLE	JFK	808	267.0	9.00	737	7	33270.	1.25	14.62
CLE	LAX	75	1668.0	18.00	D8S	7	41000.	2.30	82.66
CLE	LAX	77	1668.0	18.00	DC8	7	41000.	2.32	75.63
CLE	LGA	326	258.0	-7.00	737	7	33180.	-.97	-11.39
CLE	LGA	386	258.0	-7.00	737	1	33180.	-.97	-11.39
CLE	LGA	386	258.0	-7.00	737	6	33180.	-.97	-11.39
CLE	LGA	394	258.0	-7.00	737	7	33180.	-.97	-11.39
CLE	LGA	712	258.0	-7.00	737	7	33180.	-.97	-11.39
CLE	LGA	814	258.0	-7.00	727	7	34720.	-.91	-16.13
CLE	LGA	840	258.0	-7.00	737	7	33180.	-.97	-11.39
CLE	LGA	918	258.0	-7.00	737	1	33180.	-.97	-11.39
CLE	LGA	918	258.0	-7.00	737	6	33180.	-.97	-11.39
CLE	LGA	1232	258.0	-7.00	D10	7	34720.	-.88	-33.59
CLE	MKE	301	204.0	4.00	DC8	7	32413.	.51	15.42
CLE	MKE	701	204.0	4.00	DC8	7	32413.	.51	15.42
CLE	ORD	101	185.0	8.00	DC8	7	31400.	1.01	31.36
CLE	ORD	155	185.0	8.00	D10	7	31400.	.99	40.13
CLE	ORD	157	185.0	8.00	D10	7	31400.	.99	40.13
CLE	ORD	463	185.0	8.00	D10	7	31400.	.99	40.13
CLE	ORD	953	185.0	8.00	747	7	31400.	.98	57.28
CLE	ORD	959	185.0	8.00	DC8	7	31400.	1.01	31.36
CLE	ORD	1401	185.0	8.00	DC8	7	31400.	1.01	31.36
CLE	PHL	364	237.0	7.00	72S	7	33880.	.92	17.95
CLE	PHL	406	237.0	7.00	737	7	32920.	.97	11.44
CLE	PHL	474	237.0	7.00	727	7	33980.	.91	16.44
CLE	PHL	940	237.0	7.00	72S	7	33880.	.92	17.95
CMH	DCA	668	179.0	4.00	737	5	31373.	.55	6.74
CMH	DCA	668	179.0	4.00	737	2	31373.	.55	6.74
CMH	DCA	684	179.0	4.00	737	7	31373.	.55	6.74
DCA	BUF	898	166.0	22.00	727	7	30493.	2.61	54.68
DCA	CLE	235	188.0	26.00	737	7	31613.	3.57	43.62
DCA	CLE	357	188.0	26.00	72S	6	31560.	3.38	69.48
DCA	CLE	357	188.0	26.00	72S	1	31560.	3.38	69.48
DCA	CLE	455	188.0	26.00	737	7	31613.	3.57	43.62
DCA	CLE	779	188.0	26.00	737	7	31613.	3.57	43.62
DCA	CMH	285	207.0	27.00	737	7	32120.	3.72	44.85
DCA	CMH	847	207.0	27.00	727	7	32573.	3.48	65.09
DCA	CMH	1285	207.0	27.00	737	7	32120.	3.72	44.85
DCA	DAY	493	206.0	21.00	737	7	32093.	2.89	34.90
DCA	DAY	727	206.0	21.00	737	6	32093.	2.89	34.90
DCA	DAY	727	206.0	21.00	737	1	32093.	2.89	34.90
DCA	DTW	221	266.0	19.00	727	7	35000.	2.48	43.50
DCA	DTW	709	266.0	19.00	737	6	33260.	2.63	30.86
DCA	MSP	669	726.0	6.00	727	7	35000.	.78	13.74
DCA	ORD	207	455.0	42.00	727	7	35000.	5.48	96.16
DCA	ORD	247	455.0	42.00	72S	7	35000.	5.54	105.01
DCA	ORD	271	455.0	42.00	72S	7	35000.	5.54	105.01
DCA	ORD	277	455.0	42.00	72S	7	35000.	5.54	105.01
DCA	ORD	299	455.0	42.00	72S	7	35000.	5.54	105.01
DCA	ORD	327	455.0	42.00	727	7	35000.	5.48	96.16
DCA	ORD	667	455.0	42.00	727	6	35000.	5.48	96.16
DCA	ORD	667	455.0	42.00	727	1	35000.	5.48	96.16
DCA	PIT	649	93.0	0.00	737	7	27240.	0.00	0.00
DCA	PIT	699	93.0	0.00	737	7	27240.	0.00	0.00
DCA	PIT	787	93.0	0.00	737	7	27240.	0.00	0.00
DCA	TYS	593	287.0	2.00	737	7	33470.	.28	3.24
DCA	TYS	815	287.0	2.00	727	7	35000.	.26	4.58
DEN	BOI	311	469.0	-5.00	72S	7	35000.	-.66	-12.50
DEN	BOI	621	469.0	-5.00	72S	7	35000.	-.66	-12.50
DEN	DTW	238	913.0	4.00	D10	7	41000.	.51	16.69
DEN	DTW	460	913.0	4.00	727	7	35000.	.52	9.16
DEN	IAD	166	1214.0	11.00	727	7	35000.	1.43	25.19
DEN	IAD	606	1214.0	11.00	727	7	35000.	1.43	25.19
DEN	IAD	632	1214.0	11.00	D8S	7	41000.	1.40	50.52

TABLE G.5
UNITED AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
DEN	JFK	160	1323.0	6.00	D8S	7	41000.	.77	27.55
DEN	JFK	164	1323.0	6.00	D10	7	41000.	.76	25.03
DEN	JFK	644	1323.0	6.00	D8S	7	41000.	.77	27.55
DEN	JFK	1434	1323.0	6.00	DC8	7	41000.	.77	25.21
DEN	LAS	249	451.0	5.00	D10	7	41000.	.63	20.85
DEN	LAS	305	451.0	5.00	DC8	7	41000.	.64	21.01
DEN	LAS	753	451.0	5.00	727	7	35000.	.65	11.45
DEN	LAS	855	451.0	5.00	DC8	7	41000.	.64	21.01
DEN	LAS	965	451.0	5.00	727	7	35000.	.65	11.45
DEN	LAX	193	636.0	3.00	747	7	37000.	.38	20.68
DEN	LAX	241	636.0	3.00	D10	7	41000.	.38	12.51
DEN	LAX	701	636.0	3.00	DC8	7	41000.	.39	12.60
DEN	LAX	726	636.0	3.00	727	7	35000.	.39	6.87
DEN	LAX	799	636.0	3.00	727	7	35000.	.39	6.87
DEN	LAX	1149	636.0	3.00	727	7	35000.	.39	6.87
DEN	OMA	208	338.0	5.00	727	7	35000.	.65	11.45
DEN	OMA	340	338.0	5.00	727	7	35000.	.65	11.45
DEN	OMA	494	338.0	5.00	727	7	35000.	.65	11.45
DEN	OMA	730	338.0	5.00	72S	7	35000.	.66	12.50
DEN	ORD	222	688.0	4.00	DC8	7	41000.	.51	16.81
DEN	ORD	236	688.0	4.00	D10	7	41000.	.51	16.69
DEN	ORD	240	688.0	4.00	727	7	35000.	.52	9.16
DEN	ORD	280	688.0	4.00	D8S	7	41000.	.51	18.37
DEN	ORD	282	688.0	4.00	D10	7	41000.	.51	16.69
DEN	ORD	492	688.0	4.00	D10	7	41000.	.51	16.69
DEN	ORD	686	688.0	4.00	DC8	1	41000.	.51	16.81
DEN	ORD	870	688.0	4.00	737	7	35000.	.56	6.30
DEN	ORD	916	688.0	4.00	72S	7	35000.	.53	10.00
DEN	ORD	1410	688.0	4.00	727	7	35000.	.52	9.16
DEN	ORD	1416	688.0	4.00	D10	7	41000.	.51	16.69
DEN	ORD	4006	688.0	4.00	727	7	35000.	.52	9.16
DEN	ORD	4010	688.0	4.00	727	7	35000.	.52	9.16
DEN	PDX	167	776.0	5.00	D8S	7	41000.	.64	22.96
DEN	PDX	743	776.0	5.00	DC8	7	41000.	.64	21.01
DEN	PDX	811	776.0	5.00	727	7	35000.	.65	11.45
DEN	SEA	177	808.0	6.00	DC8	6	41000.	.77	25.21
DEN	SEA	177	808.0	6.00	DC8	1	41000.	.77	25.21
DEN	SEA	379	808.0	6.00	D10	7	41000.	.76	25.03
DEN	SFO	165	726.0	4.00	D10	7	41000.	.51	16.69
DEN	SFO	393	726.0	4.00	727	7	35000.	.52	9.16
DEN	SFO	647	726.0	4.00	72S	7	35000.	.53	10.00
DEN	SFO	801	726.0	4.00	727	7	35000.	.52	9.16
DEN	SFO	869	726.0	4.00	737	7	35000.	.56	6.30
DEN	SFO	963	726.0	4.00	72S	7	35000.	.53	10.00
DEN	SFO	1189	726.0	4.00	727	7	35000.	.52	9.16
DEN	SFO	4001	726.0	4.00	D8S	7	41000.	.51	18.37
DEN	SLC	151	245.0	2.00	DC8	7	34200.	.25	7.70
DEN	SLC	173	245.0	2.00	DC8	7	34200.	.25	7.70
DEN	SLC	761	245.0	2.00	727	7	34200.	.26	4.66
DEN	SLC	793	245.0	2.00	727	7	34200.	.26	4.66
DSM	LAX	227	1164.0	9.00	727	7	35000.	1.17	20.61
DSM	ORD	252	161.0	0.00	72S	7	30120.	0.00	0.00
DSM	ORD	272	161.0	0.00	727	7	30120.	0.00	0.00
DSM	ORD	412	161.0	0.00	72S	7	30120.	0.00	0.00
DSM	ORD	486	161.0	0.00	72S	7	30120.	0.00	0.00
DSM	ORD	662	161.0	0.00	72S	7	30120.	0.00	0.00
DSM	ORD	928	161.0	0.00	72S	7	30120.	0.00	0.00
DTW	BAL	284	248.0	0.00	727	7	34320.	0.00	0.00
DTW	BAL	766	248.0	0.00	DC8	7	34320.	0.00	0.00
DTW	DCA	442	285.0	37.00	737	7	33450.	5.12	59.90
DTW	DCA	752	265.0	37.00	737	7	33450.	5.12	59.90
DTW	DEN	249	899.0	-5.00	D10	7	41000.	-.63	-20.86
DTW	DEN	311	899.0	-5.00	72S	7	35000.	-.66	-12.50
DTW	LAX	81	1663.0	12.00	D10	7	41000.	1.52	50.06
DTW	ORD	203	101.0	-4.00	72S	7	25880.	-.51	-12.16
DTW	ORD	221	101.0	-4.00	727	7	25880.	-.50	-11.13
DTW	ORD	251	101.0	-4.00	737	7	27880.	-.54	-7.34
DTW	ORD	709	101.0	-4.00	737	6	27880.	-.54	-7.34
DTW	ORD	919	101.0	-4.00	727	7	25880.	-.50	-11.13
DTW	PHL	460	320.0	11.00	727	7	35000.	1.43	25.19
DTW	PHL	618	320.0	11.00	DC8	7	37160.	1.42	43.21
DTW	PHL	688	320.0	11.00	DC8	7	37160.	1.42	43.21
DTW	PIT	86	85.0	-1.00	D10	7	24600.	-.12	-5.75
DTW	SFO	89	1736.0	16.00	D10	7	41000.	2.28	75.09
EWR	CLE	187	268.0	8.00	DC8	4	35120.	1.02	30.97
EWR	CLE	187	268.0	8.00	DC8	2	35120.	1.02	30.97
EWR	CLE	305	268.0	8.00	DC8	7	35120.	1.02	30.97
EWR	CLE	403	268.0	8.00	737	7	33280.	1.11	12.99
EWR	CLE	421	268.0	8.00	727	7	35000.	1.04	18.32
EWR	CLE	457	268.0	8.00	DC8	7	35120.	1.02	30.97
EWR	CLE	747	268.0	8.00	737	7	33280.	1.11	12.99
EWR	CLE	1153	268.0	8.00	72S	7	35000.	1.06	20.00
EWR	GSO	569	301.0	4.00	737	7	33610.	.55	6.46
EWR	GSO	657	301.0	4.00	737	7	33610.	.55	6.46
EWR	GSO	781	301.0	4.00	727	7	35000.	.52	9.16
EWR	LAX	11	2034.0	0.00	D8S	7	41000.	0.00	0.00
EWR	LAX	19	2034.0	0.00	D8S	7	41000.	0.00	0.00
EWR	ORD	147	531.0	17.00	D10	7	41000.	2.15	70.92
EWR	ORD	201	531.0	17.00	727	7	35000.	2.22	38.92
EWR	ORD	225	531.0	17.00	D10	7	41000.	2.15	70.92
EWR	ORD	279	531.0	17.00	72S	7	35000.	2.24	42.50
EWR	ORD	543	531.0	17.00	D10	7	41000.	2.15	70.92
EWR	ORD	1199	531.0	17.00	DC8	7	41000.	2.19	71.42
EWR	SFO	35	2158.0	27.00	D8S	7	41000.	3.45	124.00
GEG	SFO	529	584.0	4.00	727	7	35000.	.52	9.16
GEG	SFO	782	584.0	4.00	727	7	35000.	.52	9.16
GEG	SFO	809	584.0	4.00	727	7	35000.	.52	9.16
GSO	EWR	298	304.0	12.00	737	7	33640.	1.66	19.36
GSO	EWR	654	304.0	12.00	737	7	33640.	1.66	19.36
GSO	EWR	780	304.0	12.00	727	7	35000.	1.57	27.47
GSO	EWR	788	304.0	12.00	737	7	33640.	1.66	19.36
IAD	DEN	167	1220.0	12.00	D8S	7	41000.	1.53	55.11
IAD	DEN	175	1220.0	12.00	727	7	35000.	1.57	27.47
IAD	DEN	743	1220.0	12.00	DC8	7	41000.	1.54	50.42
IAD	LAX	55	1947.0	22.00	D10	7	41000.	2.78	91.78
IAD	LAX	59	1947.0	22.00	D8S	7	41000.	2.81	101.03
IAD	ORD	273	455.0	42.00	727	7	35000.	5.48	96.16
IAD	ORD	673	455.0	42.00	737	5	35000.	5.86	66.15
IAD	ORD	673	455.0	42.00	737	1	35000.	5.86	66.15
IAD	SFO	53	2159.0	23.00	D8S	7	41000.	2.94	105.63
IAD	SFO	57	2159.0	23.00	D8S	7	41000.	2.94	105.63
JAX	ATL	396	148.0	2.00	72S	7	29427.	.26	5.51
JFK	BOS	644	166.0	50.00	D8S	7	26280.	6.13	237.41
JFK	CLE	773	273.0	13.00	737	7	33330.	1.80	21.09
JFK	CLE	991	273.0	13.00	737	7	33330.	1.80	21.09
JFK	CLE	1233	273.0	13.00	D10	7	35320.	1.64	62.01
JFK	DEN	165	1406.0	13.00	D10	7	41000.	1.65	54.23
JFK	DEN	173	1406.0	13.00	DC8	7	41000.	1.67	54.62
JFK	DEN	1433	1406.0	13.00	DC8	7	41000.	1.67	54.62
JFK	LAS	711	1888.0	21.00	DC8	7	41000.	2.70	88.23
JFK	LAX	5	2040.0	0.00	747	7	37000.	0.00	0.00
JFK	LAX	15	2040.0	0.00	D10	7	41000.	0.00	0.00
JFK	ORD	119	558.0	4.00	DC8	7	41000.	.51	16.81
JFK	ORD	159	558.0	4.00	DC8	7	41000.	.51	16.81
JFK	ORD	229	558.0	4.00	D8S	7	41000.	.51	18.37
JFK	ORD	239	558.0	4.00	72S	7	35000.	.53	10.00
JFK	SEA	47	2011.0	23.00	D10	7	41000.	2.91	95.95
JFK	SFO	25	2165.0	26.00	D10	7	41000.	3.29	108.46
JFK	SFO	29	2165.0	26.00	D10	7	41000.	3.29	108.46
LAS	DEN	238	458.0	6.00	D10	7	41000.	.76	25.03
LAS	DEN	454	458.0	6.00	727	7	35000.	.78	13.74
LAS	DEN	468	458.0	6.00	727	7	35000.	.78	13.74
LAS	DEN	686	458.0	6.00	DC8	1	41000.	.77	25.21
LAS	DEN	832	458.0	6.00	DC8	7	41000.	.77	25.21
LAS	DEN	962	458.0	6.00	727	7	35000.	.78	13.74
LAS	DEN	1148	458.0	6.00	727	7	35000.	.78	13.74
LAS	JFK	74	1852.0	10.00	DC8	7	41000.	1.29	42.01
LAS	LAX	229	104.0	2.00	D8S	7	26120.	.25	9.54
LAS	LAX	345	104.0	2.00	D10	7	26120.	.25	11.26
LAS	LAX	571	104.0	2.00	DC8	5	26120.	.25	8.73
LAS	LAX	857	104.0	2.00	727	7	26120.	.25	5.52
LAS	ORD	120	1233.0	12.00	DC8	2	41000.	1.54	50.42
LAS	ORD	120	1233.0	12.00	DC8	5	41000.	1.54	50.42
LAS	ORD	218	1233.0	12.00	747	7	37000.	1.50	82.73
LAS	ORD	358	1233.0	12.00	D10	7	41000.	1.52	50.06
LAS	ORD	686	1233.0	12.00	DC8	6	41000.	1.54	50.42
LAX	BAL	64	1907.0	22.00	DC8	7	41000.	2.83	92.43
LAX	CLE	74	1684.0	18.00	D8S	7	41000.	2.30	82.66
LAX	DEN	114	637.0	7.00	747	7	37000.	.88	48.26
LAX	DEN	176	637.0	7.00	72S	7	35000.	.92	17.50
LAX	DEN	414	637.0	7.00	D10	7	41000.	.89	29.20
LAX	DEN	574	637.0	7.00	727	7	35000.	.91	16.03
LAX	DSM	408	1156.0	2.00	727	7	35000.	.26	4.58
LAX	DTW	84	1619.0	15.00	D10	7	41000.	1.90	62.57
LAX	EWR	12	2032.0	24.00	D8S	7	41000.	3.07	110.22
LAX	IAD	52	1913.0	24.00	D10	7	41000.	3.04	100.12
LAX	IAD	54	1913.0	24.00	D8S	7	41000.	3.07	110.22
LAX	JFK	6	2032.0	-16.00	D10	7	41000.	-2.03	-66.75
LAX	JFK	8	2032.0	-16.00	747	7	37000.	-2.00	-110.30
LAX	LAS	120	103.0	3.00	DC8	5	26040.	.37	13.13

TABLE G.5
UNITED AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
LAX	LAS	358	103.0	3.00	D10	7	26040.	.37	16.91
LAX	LAS	454	103.0	3.00	727	7	26040.	.38	8.31
LAX	LAS	494	103.0	3.00	727	7	26040.	.38	8.31
LAX	LAS	832	103.0	3.00	DC8	7	26040.	.37	13.13
LAX	OMA	168	1057.0	9.00	725	7	35000.	1.19	22.50
LAX	OMA	304	1057.0	9.00	727	7	35000.	1.17	20.61
LAX	OMA	352	1057.0	9.00	727	6	35000.	1.17	20.61
LAX	ORD	100	1412.0	14.00	747	7	37000.	1.75	96.52
LAX	ORD	104	1412.0	14.00	D10	7	41000.	1.77	58.40
LAX	ORD	108	1412.0	14.00	D10	7	41000.	1.77	58.40
LAX	ORD	110	1412.0	14.00	DC8	7	41000.	1.80	58.82
LAX	ORD	118	1412.0	14.00	747	7	37000.	1.75	96.52
LAX	PDX	202	660.0	5.00	725	7	35000.	.66	12.50
LAX	PDX	380	660.0	5.00	DC8	7	41000.	.64	21.01
LAX	PDX	418	660.0	5.00	727	7	35000.	.65	11.45
LAX	PDX	486	660.0	5.00	727	7	35000.	.65	11.45
LAX	PDX	598	660.0	5.00	727	7	35000.	.65	11.45
LAX	PHL	88	1995.0	14.00	DC8	7	41000.	1.80	58.82
LAX	SEA	290	761.0	6.00	727	7	35000.	.78	13.74
LAX	SEA	292	761.0	6.00	727	7	35000.	.78	13.74
LAX	SEA	294	761.0	6.00	727	7	35000.	.78	13.74
LAX	SEA	308	761.0	6.00	727	7	35000.	.78	13.74
LAX	SEA	345	761.0	6.00	D10	7	41000.	.76	25.03
LAX	SEA	458	761.0	6.00	D8S	7	41000.	.77	27.55
LAX	SEA	1168	761.0	6.00	D8S	7	41000.	.77	27.55
LAX	SFO	11	199.0	17.00	D8S	7	32147.	2.13	71.97
LAX	SFO	59	199.0	17.00	D8S	7	32147.	2.13	71.97
LAX	SFO	63	199.0	17.00	DC8	7	32147.	2.15	65.84
LAX	SFO	433	199.0	17.00	727	7	32147.	2.19	41.24
LAX	SFO	502	199.0	17.00	737	7	31907.	2.34	28.36
LAX	SFO	504	199.0	17.00	727	7	32147.	2.19	41.24
LAX	SFO	506	199.0	17.00	727	7	32147.	2.19	41.24
LAX	SFO	508	199.0	17.00	737	7	31907.	2.34	28.36
LAX	SFO	510	199.0	17.00	727	7	32147.	2.19	41.24
LAX	SFO	520	199.0	17.00	727	7	32147.	2.19	41.24
LAX	SFO	522	199.0	17.00	727	7	32147.	2.19	41.24
LAX	SFO	526	199.0	17.00	737	7	31907.	2.34	28.36
LAX	SFO	528	199.0	17.00	DC8	7	32147.	2.15	65.84
LAX	SFO	530	199.0	17.00	737	7	31907.	2.34	28.36
LAX	SFO	707	199.0	17.00	727	7	32147.	2.19	41.24
LAX	SFO	815	199.0	17.00	727	7	32147.	2.19	41.24
LAX	SFO	1182	199.0	17.00	D10	7	32147.	2.11	84.18
LAX	SFO	1184	199.0	17.00	725	7	32147.	2.22	45.04
LAX	SFO	1186	199.0	17.00	747	7	32147.	2.09	119.94
LAX	SFO	1188	199.0	17.00	747	7	32147.	2.09	119.94
LGA	ATL	351	560.0	4.00	727	7	35000.	.52	9.16
LGA	CLE	145	270.0	10.00	D10	7	35200.	1.26	47.76
LGA	CLE	387	270.0	10.00	727	7	35000.	1.30	22.90
LGA	CLE	411	270.0	10.00	727	7	35000.	1.30	22.90
LGA	CLE	429	270.0	10.00	737	7	33300.	1.38	16.23
LGA	CLE	469	270.0	10.00	737	7	33300.	1.38	16.23
LGA	CLE	665	270.0	10.00	737	7	33300.	1.38	16.23
LGA	CLE	803	270.0	10.00	737	7	33300.	1.38	16.23
LGA	CLE	947	270.0	10.00	737	7	33300.	1.38	16.23
LGA	CLE	969	270.0	10.00	737	6	33300.	1.38	16.23
LGA	CLE	969	270.0	10.00	737	1	33300.	1.38	16.23
LGA	ORD	903	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ORD	911	532.0	15.00	725	7	35000.	1.98	37.50
LGA	ORD	917	532.0	15.00	725	7	35000.	1.98	37.50
LGA	ORD	921	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ORD	929	532.0	15.00	727	7	35000.	1.96	34.34
MEM	LAX	433	1379.0	13.00	727	7	35000.	1.70	29.76
MEM	LAX	815	1379.0	13.00	727	7	35000.	1.70	29.76
MIA	ATL	570	453.0	23.00	727	7	35000.	3.00	52.66
MIA	PIT	268	811.0	6.00	727	7	35000.	.78	13.74
MIA	PIT	574	811.0	6.00	D10	7	41000.	.76	25.03
MIA	PIT	1228	811.0	6.00	727	7	35000.	.78	13.74
MIA	TPA	1124	90.0	-4.00	D10	7	25000.	-.50	-22.87
MKE	CLE	306	207.0	8.00	727	7	32573.	1.03	19.29
MKE	CLE	852	207.0	8.00	727	7	32573.	1.03	19.29
MKE	DEN	241	733.0	6.00	D10	7	41000.	.76	25.03
MKE	DEN	243	733.0	6.00	DC8	7	41000.	.77	25.21
MKE	DEN	701	733.0	6.00	DC8	7	41000.	.77	25.21
MKE	DEN	1439	733.0	6.00	D8S	7	41000.	.77	27.55
MSP	DCA	656	742.0	6.00	727	7	35000.	.78	13.74
MSP	ORD	270	190.0	0.00	727	5	31667.	0.00	0.00
MSP	ORD	464	190.0	0.00	727	7	31667.	0.00	0.00
MSP	ORD	484	190.0	0.00	727	7	31667.	0.00	0.00
MSP	ORD	680	190.0	0.00	725	7	31667.	0.00	0.00
MSP	ORD	716	190.0	0.00	727	7	31667.	0.00	0.00

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
MSP	ORD	728	190.0	0.00	727	7	31667.	0.00	0.00
MSP	ORD	876	190.0	0.00	727	6	31667.	0.00	0.00
MSP	ORD	876	190.0	0.00	727	1	31667.	0.00	0.00
OMA	DEN	483	340.0	5.00	727	7	35000.	.65	11.45
OMA	DEN	647	340.0	5.00	725	7	35000.	.66	12.50
OMA	DEN	726	340.0	5.00	727	7	35000.	.65	11.45
OMA	DEN	799	340.0	5.00	727	7	35000.	.65	11.45
OMA	DEN	801	340.0	5.00	727	7	35000.	.65	11.45
OMA	DEN	825	340.0	5.00	D8S	7	37800.	.64	21.72
OMA	ORD	404	264.0	2.00	725	7	34960.	.26	5.01
OMA	ORD	430	264.0	2.00	725	7	34960.	.26	5.01
OMA	ORD	490	264.0	2.00	725	7	34960.	.26	5.01
OMA	ORD	776	264.0	2.00	D8S	7	34960.	.25	4.45
OMA	ORD	880	264.0	2.00	725	7	34960.	.26	5.01
OMA	ORD	904	264.0	2.00	725	7	34960.	.26	5.01
OMA	ORD	980	264.0	2.00	737	6	33240.	.28	3.25
OMA	ORD	980	264.0	2.00	737	1	33240.	.28	3.25
ORD	BAL	170	447.0	29.00	727	7	35000.	3.78	66.40
ORD	BAL	338	447.0	29.00	727	7	35000.	3.78	66.40
ORD	BAL	410	447.0	29.00	727	7	35000.	3.78	66.40
ORD	BAL	834	447.0	29.00	727	7	35000.	3.78	66.40
ORD	BAL	846	447.0	29.00	727	7	35000.	3.78	66.40
ORD	BDL	128	598.0	18.00	D10	7	41000.	2.28	75.09
ORD	BDL	140	598.0	18.00	D8S	7	41000.	2.30	82.66
ORD	BDL	374	598.0	18.00	DC8	7	41000.	2.32	75.63
ORD	BDL	444	598.0	18.00	D8S	7	41000.	2.30	82.66
ORD	BOS	146	656.0	-15.00	DC8	7	41000.	-1.93	-63.02
ORD	BOS	158	656.0	-15.00	D10	6	41000.	-1.90	-62.57
ORD	BOS	200	656.0	-15.00	DC8	7	41000.	-1.93	-63.02
ORD	BOS	222	656.0	-15.00	DC8	7	41000.	-1.93	-63.02
ORD	BOS	276	656.0	-15.00	DC8	7	41000.	-1.93	-63.02
ORD	BUF	330	349.0	39.00	737	7	34040.	5.42	62.43
ORD	BUF	398	349.0	39.00	737	7	34040.	5.42	62.43
ORD	BUF	736	349.0	39.00	737	7	34040.	5.42	62.43
ORD	CAK	370	230.0	45.00	737	7	32733.	6.21	73.83
ORD	CAK	552	230.0	45.00	737	7	32733.	6.21	73.83
ORD	CAK	724	230.0	45.00	737	7	32733.	6.21	73.83
ORD	CAK	876	230.0	45.00	727	6	33600.	5.83	106.37
ORD	CAK	876	230.0	45.00	727	1	33600.	5.83	106.37
ORD	CLE	152	181.0	-2.00	D8S	7	31187.	-.25	-8.60
ORD	CLE	218	181.0	-2.00	747	7	31187.	-.24	-14.38
ORD	CLE	236	181.0	-2.00	D10	7	31187.	-.25	-10.07
ORD	CLE	270	181.0	-2.00	727	5	31187.	-.26	-4.92
ORD	CLE	270	181.0	-2.00	727	2	31187.	-.26	-4.92
ORD	CLE	316	181.0	-2.00	D10	7	31187.	-.25	-10.07
ORD	CLE	364	181.0	-2.00	725	7	31187.	-.26	-5.37
ORD	CLE	916	181.0	-2.00	725	7	31187.	-.26	-5.37
ORD	CLE	1416	181.0	-2.00	D10	7	31187.	-.25	-10.07
ORD	DCA	272	444.0	25.00	727	7	35000.	3.26	57.24
ORD	DCA	278	444.0	25.00	727	7	35000.	3.26	57.24
ORD	DCA	322	444.0	25.00	725	7	35000.	3.30	62.50
ORD	DCA	328	444.0	25.00	737	5	35000.	3.49	39.38
ORD	DCA	328	444.0	25.00	737	1	35000.	3.49	39.38
ORD	DCA	412	444.0	25.00	725	7	35000.	3.30	62.50
ORD	DCA	430	444.0	25.00	725	7	35000.	3.30	62.50
ORD	DCA	488	444.0	25.00	725	7	35000.	3.30	62.50
ORD	DCA	980	444.0	25.00	737	6	35000.	3.49	39.38
ORD	DEN	203	683.0	4.00	725	7	35000.	.53	10.00
ORD	DEN	217	683.0	4.00	D10	7	41000.	.51	16.69
ORD	DEN	237	683.0	4.00	D10	7	41000.	.51	16.69
ORD	DEN	263	683.0	4.00	725	7	35000.	.53	10.00
ORD	DEN	461	683.0	4.00	D8S	7	41000.	.51	18.37
ORD	DEN	463	683.0	4.00	D10	7	41000.	.51	16.69
ORD	DEN	1407	683.0	4.00	727	7	35000.	.52	9.16
ORD	DEN	1415	683.0	4.00	D10	7	41000.	.51	16.69
ORD	DEN	1417	683.0	4.00	737	7	35000.	.56	6.30
ORD	DEN	1421	683.0	4.00	727	7	35000.	.52	9.16
ORD	DEN	4007	683.0	4.00	DC8	7	41000.	.51	16.81
ORD	DEN	4009	683.0	4.00	DC8	7	41000.	.51	16.81
ORD	DEN	4011	683.0	4.00	727	7	35000.	.52	9.16
ORD	DSM	239	159.0	2.00	725	7	30013.	.26	5.47
ORD	DSM	497	159.0	2.00	725	7	30013.	.26	5.47
ORD	DSM	667	159.0	2.00	727	6	30013.	.26	5.01
ORD	DSM	667	159.0	2.00	727	1	30013.	.26	5.01
ORD	DSM	783	159.0	2.00	737	7	30760.	.27	3.42
ORD	DSM	835	159.0	2.00	725	7	30013.	.26	5.47
ORD	DSM	917	159.0	2.00	725	7	30013.	.26	5.47
ORD	DTW	210	103.0	1.00	725	7	26040.	.13	3.02
ORD	DTW	498	103.0	1.00	737	7	28040.	.14	1.83
ORD	DTW	602	103.0	1.00	737	7	26040.	.14	1.83

TABLE G.5
UNITED AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
ORD	DTW	706	103.0	1.00	727	7	26040.	.13	2.77
ORD	DTW	752	103.0	1.00	737	7	28040.	.14	1.83
ORD	DTW	882	103.0	1.00	727	7	26040.	.13	2.77
ORD	EWR	136	516.0	-3.00	D8S	7	41000.	-.38	-13.78
ORD	EWR	142	516.0	-3.00	D10	7	41000.	-.38	-12.51
ORD	EWR	220	516.0	-3.00	DC8	7	41000.	-.39	-12.60
ORD	EWR	358	516.0	-3.00	D10	7	41000.	-.38	-12.51
ORD	EWR	492	516.0	-3.00	D10	7	41000.	-.38	-12.51
ORD	EWR	1198	516.0	-3.00	DC8	7	41000.	-.39	-12.60
ORD	JFK	120	518.0	0.00	DC8	2	41000.	0.00	0.00
ORD	JFK	120	518.0	0.00	DC8	5	41000.	0.00	0.00
ORD	JFK	252	518.0	0.00	72S	7	35000.	0.00	0.00
ORD	JFK	686	518.0	0.00	DC8	6	41000.	0.00	0.00
ORD	JFK	686	518.0	0.00	DC8	1	41000.	0.00	0.00
ORD	JFK	890	518.0	0.00	DC8	7	41000.	0.00	0.00
ORD	LAS	229	1255.0	12.00	D8S	7	41000.	1.53	55.11
ORD	LAS	345	1255.0	12.00	D10	7	41000.	1.52	50.06
ORD	LAS	723	1255.0	12.00	747	7	37000.	1.50	82.73
ORD	LAS	841	1255.0	12.00	727	7	35000.	1.57	27.47
ORD	LAX	101	1409.0	10.00	DC8	7	41000.	1.29	42.01
ORD	LAX	103	1409.0	10.00	D10	7	41000.	1.27	41.72
ORD	LAX	107	1409.0	10.00	747	7	37000.	1.25	68.94
ORD	LAX	111	1409.0	10.00	747	7	37000.	1.25	68.94
ORD	LAX	115	1409.0	10.00	D10	7	41000.	1.27	41.72
ORD	LGA	900	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	904	519.0	1.00	72S	7	35000.	.13	2.50
ORD	LGA	910	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	914	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	922	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	928	519.0	1.00	72S	7	35000.	.13	2.50
ORD	MSP	273	212.0	23.00	727	7	32840.	2.97	55.23
ORD	MSP	481	212.0	23.00	727	1	32840.	2.97	55.23
ORD	MSP	485	212.0	23.00	72S	7	32840.	3.01	60.31
ORD	MSP	661	212.0	23.00	727	7	32840.	2.97	55.23
ORD	MSP	765	212.0	23.00	727	7	32840.	2.97	55.23
ORD	MSP	929	212.0	23.00	727	7	32840.	2.97	55.23
ORD	OAK	131	1531.0	16.00	D8S	7	41000.	2.04	73.48
ORD	OAK	221	1531.0	16.00	727	7	35000.	2.09	36.63
ORD	OMA	271	263.0	-4.00	72S	7	34920.	-.53	-10.02
ORD	OMA	299	263.0	-4.00	72S	7	34920.	-.53	-10.02
ORD	OMA	321	263.0	-4.00	D8S	7	34920.	-.51	-16.90
ORD	OMA	471	263.0	-4.00	D8S	7	34920.	-.51	-16.90
ORD	OMA	671	263.0	-4.00	72S	7	34920.	-.53	-10.02
ORD	OMA	777	263.0	-4.00	727	7	34920.	-.52	-9.18
ORD	OMA	911	263.0	-4.00	72S	7	34920.	-.53	-10.02
ORD	PDX	141	1423.0	12.00	DC8	7	41000.	1.54	50.42
ORD	PDX	159	1423.0	12.00	DC8	7	41000.	1.54	50.42
ORD	PHL	144	526.0	28.00	D10	7	41000.	3.54	116.81
ORD	PHL	224	526.0	28.00	D8S	7	41000.	3.58	128.59
ORD	PHL	462	526.0	28.00	DC8	7	41000.	3.60	117.64
ORD	PHL	480	526.0	28.00	72S	7	35000.	3.70	70.01
ORD	PHL	786	526.0	28.00	D10	7	41000.	3.54	116.81
ORD	PIT	118	264.0	-2.00	747	7	34960.	-.25	-13.83
ORD	PIT	150	264.0	-2.00	D8S	7	34960.	-.25	-8.45
ORD	PIT	404	264.0	-2.00	72S	7	34960.	-.26	-5.01
ORD	PIT	484	264.0	-2.00	727	7	34960.	-.26	-4.58
ORD	PIT	776	264.0	-2.00	D8S	7	34960.	-.25	-8.45
ORD	ROC	240	386.0	23.00	727	7	35000.	3.00	52.66
ORD	SAN	171	1400.0	3.00	727	7	35000.	.39	6.87
ORD	SAN	225	1400.0	3.00	D10	7	41000.	.38	12.51
ORD	SAN	419	1400.0	3.00	727	7	35000.	.39	6.87
ORD	SEA	143	1415.0	14.00	D8S	7	41000.	1.79	64.29
ORD	SEA	147	1415.0	14.00	D10	7	41000.	1.77	58.40
ORD	SEA	155	1415.0	14.00	D10	7	41000.	1.77	58.40
ORD	SEA	157	1415.0	14.00	D10	7	41000.	1.77	58.40
ORD	SFO	121	1513.0	16.00	D8S	6	41000.	2.04	73.48
ORD	SFO	121	1513.0	16.00	D8S	1	41000.	2.04	73.48
ORD	SFO	123	1513.0	16.00	D10	7	41000.	2.03	66.75
ORD	SFO	129	1513.0	16.00	747	7	37000.	2.00	110.30
ORD	SFO	135	1513.0	16.00	D8S	7	41000.	2.04	73.48
ORD	SLC	247	1007.0	9.00	72S	7	35000.	1.19	22.50
ORD	SLC	277	1007.0	9.00	72S	7	35000.	1.19	22.50
ORD	SLC	375	1007.0	9.00	72S	7	35000.	1.19	22.50
ORD	SLC	489	1007.0	9.00	DC8	7	41000.	1.16	37.81
ORD	SLC	1411	1007.0	9.00	727	7	35000.	1.17	20.61
ORD	SLC	4075	1007.0	9.00	727	7	35000.	1.17	20.61
PBI	ATL	440	391.0	0.00	727	6	35000.	0.00	0.00
PBI	ATL	440	391.0	0.00	727	1	35000.	0.00	0.00
PBI	ATL	600	391.0	0.00	737	7	34510.	0.00	0.00

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
PDX	BOI	374	216.0	2.00	DC8	7	33040.	.25	7.64
PDX	BOI	868	216.0	2.00	727	7	33040.	.26	4.79
PDX	LAX	289	639.0	4.00	727	7	35000.	.52	9.16
PDX	LAX	377	639.0	4.00	727	7	35000.	.52	9.16
PDX	LAX	487	639.0	4.00	DC8	7	41000.	.51	16.81
PDX	LAX	739	639.0	4.00	727	7	35000.	.52	9.16
PDX	LAX	1167	639.0	4.00	DC8	7	41000.	.51	16.81
PDX	OAK	369	399.0	21.00	727	7	35000.	2.74	48.08
PDX	OAK	625	399.0	21.00	727	7	35000.	2.74	48.08
PDX	OAK	845	399.0	21.00	72S	7	35000.	2.77	52.50
PDX	ORD	142	1415.0	-7.00	D10	7	41000.	-.89	-29.20
PDX	ORD	146	1415.0	-7.00	DC8	7	41000.	-.90	-29.41
PDX	ORD	152	1415.0	-7.00	D8S	7	41000.	-.89	-32.15
PDX	SFO	283	399.0	21.00	72S	7	35000.	2.77	52.50
PDX	SFO	295	399.0	21.00	737	7	34590.	2.92	33.32
PDX	SFO	365	399.0	21.00	727	7	35000.	2.74	48.08
PDX	SFO	417	399.0	21.00	DC8	7	39688.	2.70	86.27
PDX	SFO	523	399.0	21.00	737	7	34590.	2.92	33.32
PDX	SFO	537	399.0	21.00	737	7	34590.	2.92	33.32
PHL	BUF	791	210.0	53.00	727	7	32733.	6.65	127.47
PHL	CLE	363	230.0	-1.00	737	7	32733.	-.14	-1.64
PHL	CLE	427	230.0	-1.00	72S	7	33600.	-.13	-2.58
PHL	CLE	679	230.0	-1.00	727	7	33600.	-.13	-2.36
PHL	CLE	701	230.0	-1.00	DC8	7	33600.	-.13	-3.83
PHL	DTW	311	326.0	14.00	72S	7	35000.	1.85	35.00
PHL	DTW	571	326.0	14.00	DC8	5	37352.	1.80	55.19
PHL	DTW	571	326.0	14.00	DC8	1	37352.	1.80	55.19
PHL	DTW	875	326.0	14.00	DC8	7	37352.	1.80	55.19
PHL	LAX	99	2025.0	23.00	DC8	7	41000.	2.96	96.63
PHL	ORD	123	509.0	16.00	D10	7	41000.	2.03	66.75
PHL	ORD	133	509.0	16.00	D8S	7	41000.	2.04	73.48
PHL	ORD	325	509.0	16.00	72S	7	35000.	2.11	40.00
PHL	ORD	345	509.0	16.00	D10	7	41000.	2.03	66.75
PHL	ORD	841	509.0	16.00	727	7	35000.	2.09	36.63
PHL	SFO	67	2133.0	25.00	D8S	7	41000.	3.19	114.81
PIT	ABE	440	131.0	3.00	727	6	28280.	.38	7.77
PIT	ATL	459	388.0	19.00	737	7	34480.	2.64	30.21
PIT	ATL	491	388.0	19.00	727	7	35000.	2.48	43.50
PIT	ATL	589	388.0	19.00	737	7	34480.	2.64	30.21
PIT	ATL	599	388.0	19.00	737	7	34480.	2.64	30.21
PIT	DCA	370	104.0	7.00	737	7	28120.	.95	12.77
PIT	DCA	638	104.0	7.00	737	7	28120.	.95	12.77
PIT	DCA	658	104.0	7.00	727	7	26120.	.88	19.33
PIT	DCA	960	104.0	7.00	737	7	28120.	.95	12.77
PIT	FLL	905	810.0	17.00	D8S	7	41000.	2.17	78.07
PIT	FLL	979	810.0	17.00	727	7	35000.	2.22	38.92
PIT	MIA	315	809.0	6.00	727	7	35000.	.78	13.74
PIT	MIA	563	809.0	6.00	D10	7	41000.	.76	25.03
PIT	MIA	1127	809.0	6.00	D10	7	41000.	.76	25.03
PIT	MIA	1227	809.0	6.00	727	7	35000.	.78	13.74
PIT	ORD	107	267.0	10.00	747	7	35080.	1.24	69.14
PIT	ORD	143	267.0	10.00	D8S	7	35080.	1.27	42.30
PIT	ORD	401	267.0	10.00	727	7	35000.	1.30	22.90
PIT	ORD	461	267.0	10.00	D8S	7	35080.	1.27	42.30
PIT	ORD	676	267.0	10.00	737	6	33270.	1.38	16.24
PIT	ORD	765	267.0	10.00	727	7	35000.	1.30	22.90
RNO	LAX	223	259.0	13.00	DC8	7	34760.	1.66	50.21
RNO	SFO	615	104.0	42.00	727	1	26120.	5.29	116.00
RNO	SFO	757	104.0	42.00	72S	7	26120.	5.35	126.67
RNO	SFO	819	104.0	42.00	727	7	26120.	5.29	116.00
RNO	SFO	903	104.0	42.00	727	7	26120.	5.29	116.00
ROC	ORD	785	366.0	3.00	737	7	34260.	.42	4.79
ROC	ORD	899	366.0	3.00	727	7	35000.	.39	6.87
SAN	ORD	200	1440.0	15.00	DC8	7	41000.	1.93	63.02
SAN	ORD	216	1440.0	15.00	DC8	7	41000.	1.93	63.02
SAN	ORD	786	1440.0	15.00	D10	7	41000.	1.90	62.57
SAN	SFO	1176	288.0	0.00	727	7	35000.	0.00	0.00
SEA	DEN	162	808.0	6.00	D10	7	41000.	.76	25.03
SEA	DEN	174	808.0	6.00	DC8	7	41000.	.77	25.21
SEA	LAX	337	765.0	0.00	D10	7	41000.	0.00	0.00
SEA	LAX	347	765.0	0.00	DC8	7	41000.	0.00	0.00
SEA	LAX	353	765.0	0.00	72S	7	35000.	0.00	0.00
SEA	LAX	373	765.0	0.00	72S	7	35000.	0.00	0.00
SEA	LAX	381	765.0	0.00	727	7	35000.	0.00	0.00
SEA	LAX	383	765.0	0.00	727	7	35000.	0.00	0.00
SEA	ORD	140	1404.0	4.00	D8S	7	41000.	.51	18.37
SEA	ORD	144	1404.0	4.00	D10	7	41000.	.51	16.69
SEA	ORD	150	1404.0	4.00	D8S	7	41000.	.51	18.37
SEA	ORD	158	1404.0	4.00	D10	1	41000.	.51	16.69

TABLE G.5

UNITED AIRLINES

ENROUTE RNAV BENEFITS ANALYSIS

Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
SEA	ORD	154	1404.0	4.00	D10	6	41000.	.51	16.69
SEA	SFO	245	507.0	19.00	727	7	35000.	2.48	43.50
SEA	SFO	257	507.0	19.00	727	5	35000.	2.48	43.50
SEA	SFO	257	507.0	19.00	727	2	35000.	2.48	43.50
SEA	SFO	275	507.0	19.00	727	7	35000.	2.48	43.50
SEA	SFO	339	507.0	19.00	727	7	35000.	2.48	43.50
SEA	SFO	352	507.0	19.00	727	6	35000.	2.48	43.50
SEA	SFO	352	507.0	19.00	727	1	35000.	2.48	43.50
SEA	SFO	345	507.0	19.00	727	7	35000.	2.48	43.50
SEA	SFO	846	507.0	19.00	727	6	35000.	2.48	43.50
SEA	SFO	1177	507.0	19.00	727	7	35000.	2.48	43.50
SFO	BOS	94	2275.0	24.00	D8S	7	41000.	3.70	133.18
SFO	DEN	256	726.0	-2.00	727	7	35000.	-.26	-4.58
SFO	DEN	262	726.0	-2.00	DC8	7	41000.	-.26	-8.40
SFO	DEN	282	726.0	-2.00	D10	7	41000.	-.25	-8.34
SFO	DEN	730	726.0	-2.00	72S	7	35000.	-.26	-5.00
SFO	DEN	742	726.0	-2.00	727	7	35000.	-.26	-4.58
SFO	DEN	4000	726.0	-2.00	DC8	7	41000.	-.26	-8.40
SFO	EWR	34	2326.0	26.00	D8S	7	41000.	3.32	119.40
SFO	GEG	504	545.0	4.00	727	7	35000.	.52	9.16
SFO	GEG	756	545.0	4.00	727	7	35000.	.52	9.16
SFO	IAD	50	2010.0	7.00	D8S	7	41000.	.89	32.15
SFO	IAD	56	2010.0	7.00	D8S	7	41000.	.89	32.15
SFO	JFK	22	2129.0	26.00	D10	7	41000.	3.29	108.46
SFO	JFK	26	2129.0	26.00	D10	7	41000.	3.29	108.46
SFO	LAX	64	182.0	3.00	DC8	7	31240.	.38	11.79
SFO	LAX	283	182.0	3.00	72S	7	31240.	.39	8.05
SFO	LAX	352	182.0	3.00	727	6	31240.	.39	7.38
SFO	LAX	352	182.0	3.00	727	1	31240.	.39	7.38
SFO	LAX	507	182.0	3.00	727	7	31240.	.39	7.38
SFO	LAX	509	182.0	3.00	737	7	31453.	.41	5.05
SFO	LAX	519	182.0	3.00	737	7	31453.	.41	5.05
SFO	LAX	523	182.0	3.00	737	7	31453.	.41	5.05
SFO	LAX	525	182.0	3.00	D8S	7	31240.	.37	12.89
SFO	LAX	527	182.0	3.00	727	7	31240.	.39	7.38
SFO	LAX	529	182.0	3.00	727	7	31240.	.39	7.38
SFO	LAX	533	182.0	3.00	737	7	31453.	.41	5.05
SFO	LAX	610	182.0	3.00	727	7	31240.	.39	7.38
SFO	LAX	700	182.0	3.00	727	7	31240.	.39	7.38
SFO	LAX	780	182.0	3.00	727	7	31240.	.39	7.38
SFO	LAX	782	182.0	3.00	727	7	31240.	.39	7.38
SFO	LAX	896	182.0	3.00	727	6	31240.	.39	7.38
SFO	LAX	1181	182.0	3.00	D10	7	31240.	.37	15.09
SFO	LAX	1185	182.0	3.00	747	7	31240.	.37	21.55
SFO	LAX	1187	182.0	3.00	747	7	31240.	.37	21.55
SFO	LAX	1189	182.0	3.00	727	7	31240.	.39	7.38
SFO	ORD	126	1498.0	16.00	747	7	37000.	2.00	110.30
SFO	ORD	128	1498.0	16.00	D10	7	41000.	2.03	66.75
SFO	ORD	130	1498.0	16.00	D8S	7	41000.	2.04	73.48
SFO	ORD	136	1498.0	16.00	D8S	7	41000.	2.04	73.48
SFO	PDX	462	380.0	1.00	727	7	35000.	.13	2.29
SFO	PDX	508	380.0	1.00	737	7	34400.	.14	1.59
SFO	PDX	554	380.0	1.00	737	6	34400.	.14	1.59
SFO	PDX	774	380.0	1.00	727	7	35000.	.13	2.29
SFO	PDX	878	380.0	1.00	737	7	34400.	.14	1.59
SFO	SEA	242	492.0	3.00	727	7	35000.	.39	6.87
SFO	SEA	288	492.0	3.00	DC8	7	41000.	.39	12.60
SFO	SEA	388	492.0	3.00	727	7	35000.	.39	6.87
SFO	SEA	420	492.0	3.00	727	7	35000.	.39	6.87
SFO	SEA	520	492.0	3.00	727	7	35000.	.39	6.87
SFO	SEA	696	492.0	3.00	727	7	35000.	.39	6.87
SFO	SEA	707	492.0	3.00	727	7	35000.	.39	6.87
SFO	SEA	1176	492.0	3.00	727	7	35000.	.39	6.87
SFO	SLC	302	425.0	9.00	727	7	35000.	1.17	20.61
SFO	SLC	704	425.0	9.00	727	7	35000.	1.17	20.61
SFO	SLC	812	425.0	9.00	737	7	34850.	1.25	14.21
SFO	SLC	946	425.0	9.00	727	7	35000.	1.17	20.61
SLC	BOI	277	164.0	-2.00	72S	7	30280.	-.26	-5.44
SLC	BOI	375	164.0	-2.00	72S	7	30280.	-.26	-5.44
SLC	BOI	567	164.0	-2.00	72S	7	30280.	-.26	-5.44
SLC	BOI	761	164.0	-2.00	727	7	30280.	-.26	-4.99
SLC	DEN	166	245.0	0.00	727	7	34200.	0.00	0.00
SLC	DEN	178	245.0	0.00	DC8	7	34200.	0.00	0.00
SLC	DEN	226	245.0	0.00	727	7	34200.	0.00	0.00
SLC	DEN	812	245.0	0.00	737	7	33050.	0.00	0.00
SLC	DEN	946	245.0	0.00	727	7	34200.	0.00	0.00
SLC	ORD	220	991.0	5.00	DC8	7	41000.	.64	21.01
SLC	ORD	276	991.0	5.00	DC8	7	41000.	.64	21.01
SLC	ORD	274	991.0	5.00	727	7	35000.	.65	11.45
SLC	ORD	374	991.0	5.00	DC8	7	41000.	.64	21.01

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
SLC	ORD	1412	991.0	5.00	727	7	35000.	.65	11.45
SLC	SFO	137	425.0	13.00	727	7	35000.	1.70	29.76
SLC	SFO	329	425.0	13.00	DC8	7	40520.	1.67	54.17
TPA	ATL	476	301.0	35.00	72S	7	35000.	4.62	87.51
TPA	ATL	478	301.0	35.00	737	7	33610.	4.65	56.51
TPA	ATL	758	301.0	35.00	737	7	33610.	4.65	56.51
TPA	CLE	182	728.0	5.00	D10	7	41000.	.63	20.86
TPA	CLE	580	728.0	5.00	72S	7	35000.	.66	12.50
TYS	DCA	550	294.0	14.00	727	7	35000.	1.83	32.05
TYS	DCA	610	294.0	14.00	727	7	35000.	1.83	32.05

TABLE G.6
TRANS WORLD AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
ABQ	LAX	217	485.0	-3.00	72S	7	35000.	-.40	-7.50
ABQ	LAX	231	485.0	-3.00	72S	7	35000.	-.40	-7.50
ABQ	LAX	315	485.0	-3.00	72S	1	35000.	-.40	-7.50
ABQ	LAX	315	485.0	-3.00	72S	6	35000.	-.40	-7.50
ABQ	PHX	163	197.0	-2.00	727	6	32040.	-.26	-4.86
ABQ	PHX	303	197.0	-2.00	72S	7	32040.	-.26	-5.31
ATL	STL	529	360.0	29.00	DC9	7	34200.	3.82	46.09
ATL	STL	535	360.0	29.00	DC9	7	34200.	3.82	46.09
ATL	STL	537	360.0	29.00	DC9	7	34200.	3.82	46.09
BAL	ORD	169	436.0	22.00	707	7	40872.	2.81	84.12
BAL	ORD	243	436.0	22.00	707	7	40872.	2.81	84.12
BAL	ORD	381	436.0	22.00	727	7	35000.	2.87	50.37
BDL	ORD	175	589.0	-2.00	B3J	7	41000.	-.25	-8.37
BDL	ORD	403	589.0	-2.00	72S	7	35000.	-.26	-5.00
BOS	JFK	9	76.0	17.00	B3J	7	23880.	2.04	77.19
BOS	JFK	911	76.0	17.00	B3J	7	23880.	2.04	77.19
BOS	LAX	23	2214.0	27.00	L10	7	41000.	3.34	120.52
BOS	LAX	753	2214.0	27.00	L10	7	41000.	3.34	120.52
BOS	ORD	117	660.0	-4.00	707	7	41000.	-.51	-15.33
BOS	ORD	195	660.0	-4.00	L10	7	41000.	-.49	-17.85
BOS	ORD	265	660.0	-4.00	72S	7	35000.	-.53	-10.00
BOS	ORD	435	660.0	-4.00	727	7	35000.	-.52	-9.16
BOS	ORD	811	660.0	-4.00	B3J	4	41000.	-.49	-16.74
BOS	ORD	811	660.0	-4.00	B3J	3	41000.	-.49	-16.74
BOS	PIT	173	353.0	25.00	727	6	35000.	3.26	57.24
BOS	PIT	429	353.0	25.00	727	7	35000.	3.26	57.24
BOS	PIT	551	353.0	25.00	DC9	7	34130.	3.29	39.78
BOS	SFO	33	2299.0	28.00	L10	7	41000.	3.46	124.98
BOS	STL	107	881.0	7.00	707	7	41000.	.89	26.82
BOS	STL	137	881.0	7.00	707	7	41000.	.89	26.82
BOS	STL	145	861.0	7.00	727	7	35000.	.91	16.03
CLE	JFK	700	267.0	9.00	72S	7	35000.	1.19	22.50
CLE	STL	199	345.0	10.00	DC9	7	34050.	1.32	15.94
CLE	STL	577	345.0	10.00	DC9	1	34050.	1.32	15.94
CLE	STL	577	345.0	10.00	DC9	6	34050.	1.32	15.94
CLE	STL	703	345.0	10.00	B3J	7	37960.	1.23	39.69
CMH	DCA	294	179.0	4.00	72S	7	31080.	.52	10.76
CMH	DCA	426	179.0	4.00	727	7	31080.	.51	9.86
CMH	DCA	434	179.0	4.00	72S	7	31080.	.52	10.76
CMH	LGA	112	318.0	10.00	727	7	35000.	1.30	22.90
CMH	LGA	124	318.0	10.00	727	7	35000.	1.30	22.90
CMH	LGA	539	318.0	10.00	727	7	35000.	1.30	22.90
DCA	CMH	279	207.0	27.00	72S	7	32573.	3.53	71.08
DCA	CMH	441	207.0	27.00	72S	7	32573.	3.53	71.08
DCA	CMH	531	207.0	27.00	72S	1	32573.	3.53	71.08
DCA	CMH	531	207.0	27.00	72S	6	32573.	3.53	71.08
DCA	DAY	373	206.0	21.00	72S	6	32520.	2.74	55.33
DCA	ORD	183	455.0	42.00	727	7	35000.	5.48	96.16
DCA	ORD	217	455.0	42.00	72S	7	35000.	5.54	105.01
DCA	ORD	237	455.0	42.00	727	7	35000.	5.48	96.16
DCA	ORD	377	455.0	42.00	72S	7	35000.	5.54	105.01
DCA	ORD	423	455.0	42.00	72S	7	35000.	5.54	105.01
DCA	ORD	433	455.0	42.00	72S	7	35000.	5.54	105.01
DCA	ORD	449	455.0	42.00	72S	7	35000.	5.54	105.01
DCA	STL	407	544.0	4.00	72S	7	35000.	.53	10.00
DCA	STL	431	544.0	4.00	72S	7	35000.	.53	10.00
DCA	STL	459	544.0	4.00	727	7	35000.	.52	9.16
DCA	STL	461	544.0	4.00	727	7	35000.	.52	9.16
DCA	STL	561	544.0	4.00	727	7	35000.	.52	9.16
DEN	IAD	252	1214.0	11.00	727	7	35000.	1.43	25.19
DEN	JFK	132	1323.0	6.00	B3J	7	41000.	.74	25.10
DEN	JFK	154	1323.0	6.00	B3J	7	41000.	.74	25.10
DEN	JFK	156	1323.0	6.00	L10	7	41000.	.74	26.78
DEN	ORD	276	688.0	4.00	707	7	41000.	.51	15.33
DEN	ORD	278	688.0	4.00	707	7	41000.	.51	15.33
DEN	ORD	290	688.0	4.00	727	7	35000.	.52	9.16
DEN	ORD	292	688.0	4.00	727	1	35000.	.52	9.16
DEN	ORD	292	688.0	4.00	727	6	35000.	.52	9.16
DEN	ORD	366	688.0	4.00	727	7	35000.	.52	9.16
DEN	SFO	173	726.0	4.00	727	1	35000.	.52	9.16
DEN	SFO	173	726.0	4.00	727	6	35000.	.52	9.16
DEN	SFO	185	726.0	4.00	B3J	7	41000.	.49	16.74
DEN	SFO	389	726.0	4.00	B3J	7	41000.	.49	16.74
DEN	STL	108	599.0	5.00	707	7	41000.	.64	19.16
DEN	STL	430	599.0	5.00	72S	7	35000.	.66	12.50
DEN	STL	444	599.0	5.00	707	7	41000.	.64	19.16
DEN	STL	456	599.0	5.00	707	7	41000.	.64	19.16
DTW	STL	167	327.0	26.00	707	7	37384.	3.32	93.54
DTW	STL	187	327.0	26.00	707	6	37384.	3.32	93.54
DTW	STL	419	327.0	26.00	707	7	37384.	3.32	93.54
DTW	STL	903	327.0	26.00	727	1	35000.	3.39	59.53
DTW	STL	903	327.0	26.00	727	2	35000.	3.39	59.53
DTW	STL	903	327.0	26.00	727	2	35000.	3.39	59.53
EWR	LAX	61	2034.0	0.00	707	7	41000.	0.00	0.00
EWR	ORD	109	531.0	17.00	707	7	41000.	2.17	65.15
EWR	ORD	193	531.0	17.00	707	7	41000.	2.17	65.15
EWR	ORD	387	531.0	17.00	727	7	35000.	2.22	38.92
EWR	PIT	305	193.0	4.00	DC9	6	31747.	.52	6.65
EWR	PIT	305	193.0	4.00	DC9	1	31747.	.52	6.66
EWR	PIT	397	193.0	4.00	727	7	31827.	.51	9.75
EWR	PIT	401	193.0	4.00	707	7	31827.	.50	14.20
EWR	PIT	527	193.0	4.00	727	7	31827.	.51	9.75
EWR	PIT	575	193.0	4.00	DC9	7	31747.	.52	6.66
EWR	STL	239	675.0	5.00	707	7	41000.	.64	19.16
EWR	STL	247	675.0	5.00	DC9	7	35000.	.66	7.83
IAD	DEN	203	1220.0	12.00	727	7	35000.	1.57	27.47
IAD	JFK	900	100.0	-1.00	B3J	2	25800.	-.12	-4.39
IAD	JFK	900	100.0	-1.00	B3J	5	25800.	-.12	-4.39
IAD	LAX	19	1947.0	22.00	L10	7	41000.	2.72	98.20
IAD	LAX	99	1947.0	22.00	B3J	7	41000.	2.71	92.05
IAD	LAX	891	1947.0	22.00	B3J	7	41000.	2.71	92.05
IAD	SFO	63	2159.0	23.00	B3J	7	41000.	2.83	96.23
IAD	SFO	67	2159.0	23.00	B3J	7	41000.	2.83	96.23
ICT	ORD	346	409.0	0.00	72S	1	35000.	0.00	0.00
ICT	ORD	346	409.0	0.00	72S	6	35000.	0.00	0.00
ICT	ORD	376	409.0	0.00	72S	7	35000.	0.00	0.00
ICT	ORD	398	409.0	0.00	72S	6	35000.	0.00	0.00
IND	STL	139	109.0	0.00	707	7	26520.	0.00	0.00
IND	STL	181	109.0	0.00	727	1	26520.	0.00	0.00
IND	STL	181	109.0	0.00	727	6	26520.	0.00	0.00
IND	STL	223	109.0	0.00	707	7	26520.	0.00	0.00
IND	STL	305	109.0	0.00	DC9	6	28520.	0.00	0.00
IND	STL	531	109.0	0.00	72S	1	26520.	0.00	0.00
JFK	BOS	44	106.0	50.00	B3J	7	26280.	5.90	216.30
JFK	BOS	192	106.0	50.00	B3J	1	26280.	5.90	216.30
JFK	CLE	703	273.0	13.00	B3J	7	35320.	1.59	50.18
JFK	DEN	155	1406.0	13.00	B3J	7	41000.	1.60	54.39
JFK	DEN	165	1406.0	13.00	B3J	7	41000.	1.60	54.39
JFK	DEN	215	1406.0	13.00	L10	7	41000.	1.61	58.03
JFK	DTW	903	338.0	1.00	727	1	35000.	.13	2.29
JFK	DTW	903	338.0	1.00	727	2	35000.	.13	2.29
JFK	DTW	903	333.0	1.00	727	2	35000.	.13	2.29
JFK	IAD	63	104.0	3.00	B3J	7	26120.	.35	13.04
JFK	LAS	149	1888.0	21.00	L10	7	41000.	2.60	93.74
JFK	LAX	1	2040.0	0.00	707	7	41000.	0.00	0.00
JFK	LAX	7	2040.0	0.00	L10	7	41000.	0.00	0.00
JFK	LAX	9	2040.0	0.00	B3J	7	41000.	0.00	0.00
JFK	LAX	11	2040.0	0.00	B3J	7	41000.	0.00	0.00
JFK	ORD	289	558.0	4.00	707	7	41000.	.51	15.33
JFK	ORD	405	558.0	4.00	707	7	41000.	.51	15.33
JFK	PHX	17	1781.0	19.00	707	7	41000.	2.43	72.81
JFK	PHX	191	1781.0	19.00	B3J	7	41000.	2.34	79.50
JFK	SFO	41	2165.0	26.00	L10	7	41000.	3.22	116.06
JFK	SFO	43	2165.0	26.00	B3J	7	41000.	3.20	108.78
JFK	SFO	49	2165.0	26.00	L10	7	41000.	3.22	116.06
JFK	STL	447	681.0	5.00	72S	7	35000.	.66	12.50
LAS	ABQ	306	486.0	3.00	72S	7	35000.	.40	7.50
LAS	ABQ	440	486.0	3.00	72S	7	35000.	.40	7.50
LAS	ABQ	458	486.0	3.00	707	7	41000.	.38	11.50
LAS	JFK	148	1852.0	10.00	L10	7	41000.	1.24	44.64
LAS	LAX	417	104.0	2.00	72S	7	26120.	.25	6.03
LAS	ORD	102	1233.0	12.00	L10	7	41000.	1.48	53.56
LAS	ORD	196	1233.0	12.00	727	7	35000.	1.57	27.47
LAS	ORD	198	1233.0	12.00	72S	7	35000.	1.58	30.00
LAS	ORD	780	1233.0	12.00	L10	7	41000.	1.48	53.56
LAS	PHX	192	140.0	9.00	B3J	6	29000.	1.07	36.49
LAS	PHX	192	140.0	9.00	B3J	1	29000.	1.07	36.49
LAS	PHX	464	140.0	9.00	72S	1	29000.	1.16	24.95
LAS	PHX	464	140.0	9.00	72S	6	29000.	1.16	24.95
LAS	PHX	910	140.0	9.00	707	7	29000.	1.11	33.42
LAS	SFO	333	293.0	0.00	72S	7	35000.	0.00	0.00
LAS	SFO	419	293.0	0.00	707	7	36120.	0.00	0.00
LAX	BOS	754	2180.0	26.00	747	7	37000.	3.25	179.24
LAX	EWR	6	2032.0	24.00	707	7	41000.	3.07	91.97
LAX	IAD	18	1913.0	24.00	707	7	41000.	3.07	91.97
LAX	IAD	74	1913.0	24.00	B3J	7	41000.	2.95	100.42
LAX	JFK	8	2032.0	-16.00	707	7	41000.	-2.05	-61.31
LAX	JFK	702	2032.0	-16.00	B3J	7	41000.	-1.97	-66.94
LAX	JFK	840	2032.0	-16.00	747	7	37000.	-2.00	-110.30
LAX	JFK	904	2032.0	-16.00	L10	2	41000.	-1.98	-71.42

TABLE G.6
TRANS WORLD AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
LAX	JFK	904	2032.0	-16.00	L10	2	41000.	-1.98	-71.42
LAX	LAS	306	103.0	3.00	725	7	26040.	.38	9.07
LAX	LAS	454	103.0	3.00	725	6	26040.	.38	9.07
LAX	OKC	232	936.0	7.00	707	1	41000.	.89	26.82
LAX	OKC	232	936.0	7.00	707	6	41000.	.89	26.82
LAX	OKC	460	936.0	7.00	707	7	41000.	.89	26.82
LAX	ORD	20	1412.0	14.00	B3J	7	41000.	1.72	58.58
LAX	ORD	24	1412.0	14.00	707	7	41000.	1.79	53.65
LAX	ORD	26	1412.0	14.00	707	7	41000.	1.79	53.65
LAX	ORD	28	1412.0	14.00	707	7	41000.	1.79	53.65
LAX	ORD	36	1412.0	14.00	L10	7	41000.	1.73	62.49
LAX	PHL	38	1995.0	14.00	L10	7	41000.	1.73	62.49
LAX	PHX	16	208.0	0.00	B3J	7	32627.	0.00	0.00
LAX	PHX	88	208.0	0.00	707	7	32627.	0.00	0.00
LAX	PHX	190	208.0	0.00	707	7	32627.	0.00	0.00
LAX	PHX	412	208.0	0.00	725	7	32627.	0.00	0.00
LAX	SFO	53	199.0	17.00	707	7	32147.	2.13	60.05
LAX	SFO	61	199.0	17.00	707	7	32147.	2.13	60.05
LAX	SFO	107	199.0	17.00	707	7	32147.	2.13	60.05
LAX	SFO	471	199.0	17.00	707	7	32147.	2.13	60.05
LAX	SFO	761	199.0	17.00	L10	7	32147.	2.07	90.08
LAX	SFO	811	199.0	17.00	B3J	4	32147.	2.05	65.57
LAX	SFO	811	199.0	17.00	B3J	3	32147.	2.05	65.57
LAX	STL	72	1304.0	12.00	707	7	41000.	1.53	45.99
LAX	STL	76	1304.0	12.00	707	7	41000.	1.53	45.99
LAX	STL	136	1304.0	12.00	725	7	35000.	1.58	30.00
LAX	STL	448	1304.0	12.00	L10	7	41000.	1.48	53.56
LAX	TUS	106	288.0	0.00	725	7	35000.	0.00	0.00
LGA	DAY	129	385.0	13.00	725	7	35000.	1.72	32.50
LGA	DAY	411	385.0	13.00	DC9	7	34450.	1.71	20.57
LGA	DAY	465	385.0	13.00	727	7	35000.	1.70	29.76
LGA	DAY	475	385.0	13.00	DC9	7	34450.	1.71	20.57
LGA	ORD	303	532.0	15.00	725	7	35000.	1.98	37.50
LGA	ORD	315	532.0	15.00	725	6	35000.	1.98	37.50
LGA	ORD	319	532.0	15.00	725	7	35000.	1.98	37.50
LGA	ORD	323	532.0	15.00	725	7	35000.	1.98	37.50
LGA	ORD	329	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ORD	333	532.0	15.00	725	7	35000.	1.98	37.50
LGA	ORD	339	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ORD	341	532.0	15.00	727	6	35000.	1.96	34.34
LGA	ORD	343	532.0	15.00	727	7	35000.	1.96	34.34
LGA	ORD	347	532.0	15.00	725	7	35000.	1.98	37.50
LGA	ORD	351	532.0	15.00	725	7	35000.	1.98	37.50
LGA	ORD	355	532.0	15.00	725	6	35000.	1.98	37.50
LGA	ORD	359	532.0	15.00	725	7	35000.	1.98	37.50
LGA	PIT	115	201.0	12.00	DC9	7	31960.	1.56	19.89
LGA	PIT	197	201.0	12.00	DC9	7	31960.	1.56	19.89
LGA	PIT	225	201.0	12.00	727	7	32253.	1.55	29.07
LGA	PIT	251	201.0	12.00	DC9	7	31960.	1.56	19.89
LGA	PIT	253	201.0	12.00	DC9	7	31960.	1.56	19.89
LGA	PIT	515	201.0	12.00	DC9	7	31960.	1.56	19.89
LGA	PIT	541	201.0	12.00	DC9	7	31960.	1.56	19.89
LGA	SDF	393	483.0	15.00	727	7	35000.	1.96	34.34
LGA	STL	147	675.0	5.00	725	7	35000.	.66	12.50
LGA	STL	171	675.0	5.00	DC9	7	35000.	.66	7.83
LGA	STL	467	675.0	5.00	725	7	35000.	.66	12.50
LGA	STL	495	675.0	5.00	727	7	35000.	.65	11.45
MIA	STL	493	861.0	7.00	725	7	35000.	.92	17.50
MIA	STL	497	851.0	7.00	B3J	7	41000.	.86	29.29
MIA	TPA	485	90.0	-4.00	725	7	25000.	-.51	-12.49
MIA	TPA	487	90.0	-4.00	725	7	25000.	-.51	-12.49
OKC	LAX	107	925.0	-3.00	707	7	41000.	-.38	-11.50
OKC	LAX	187	925.0	-3.00	707	1	41000.	-.38	-11.50
OKC	LAX	187	925.0	-3.00	707	6	41000.	-.38	-11.50
ORD	ABQ	243	882.0	7.00	707	7	41000.	.89	26.82
ORD	ABQ	303	882.0	7.00	725	7	35000.	.92	17.50
ORD	ABQ	373	882.0	7.00	725	1	35000.	.92	17.50
ORD	ABQ	433	882.0	7.00	725	7	35000.	.92	17.50
ORD	BAL	24	447.0	29.00	707	7	41000.	3.71	111.13
ORD	BAL	92	447.0	29.00	707	7	41000.	3.71	111.13
ORD	BAL	360	447.0	29.00	727	7	35000.	3.78	66.40
ORD	BDL	82	598.0	18.00	B3J	7	41000.	2.21	75.31
ORD	BDL	262	598.0	18.00	725	7	35000.	2.38	45.00
ORD	BOS	102	656.0	-15.00	L10	7	41000.	-1.86	-66.95
ORD	BOS	106	656.0	-15.00	725	7	35000.	-1.98	-37.50
ORD	BOS	202	656.0	-15.00	B3J	7	41000.	-1.85	-62.76
ORD	BOS	242	656.0	-15.00	727	7	35000.	-1.96	-34.34
ORD	BOS	428	656.0	-15.00	707	7	41000.	-1.92	-57.48
ORD	DCA	168	444.0	25.00	725	7	35000.	3.30	62.50
ORD	DCA	198	444.0	25.00	725	7	35000.	3.30	62.50
ORD	DCA	358	444.0	25.00	L10	7	41000.	3.09	111.59
ORD	DCA	376	444.0	25.00	725	7	35000.	3.30	62.50
ORD	DCA	414	444.0	25.00	725	7	35000.	3.30	62.50
ORD	DCA	438	444.0	25.00	727	7	35000.	3.26	57.24
ORD	DEN	121	683.0	4.00	727	1	35000.	.52	9.16
ORD	DEN	121	683.0	4.00	727	6	35000.	.52	9.16
ORD	DEN	193	683.0	4.00	707	7	41000.	.51	15.33
ORD	DEN	387	683.0	4.00	727	7	35000.	.52	9.16
ORD	DEN	415	683.0	4.00	707	7	41000.	.51	15.33
ORD	DEN	423	683.0	4.00	725	7	35000.	.53	10.00
ORD	EWR	130	516.0	-3.00	B3J	7	41000.	-.37	-12.55
ORD	EWR	384	516.0	-3.00	707	7	41000.	-.38	-11.50
ORD	EWR	386	516.0	-3.00	725	7	35000.	-.40	-7.50
ORD	ICT	217	419.0	5.00	725	7	35000.	.66	12.50
ORD	ICT	315	419.0	5.00	725	1	35000.	.66	12.50
ORD	ICT	315	419.0	5.00	725	6	35000.	.66	12.50
ORD	ICT	351	419.0	5.00	725	7	35000.	.66	12.50
ORD	JFK	800	518.0	0.00	707	4	41000.	0.00	0.00
ORD	JFK	800	518.0	0.00	707	3	41000.	0.00	0.00
ORD	JFK	880	518.0	0.00	727	7	35000.	0.00	0.00
ORD	LAS	195	1255.0	12.00	L10	7	41000.	1.48	53.56
ORD	LAS	377	1255.0	12.00	725	7	35000.	1.58	30.00
ORD	LAS	403	1255.0	12.00	725	7	35000.	1.58	30.00
ORD	LAS	711	1255.0	12.00	L10	7	41000.	1.48	53.56
ORD	LAX	3	1409.0	10.00	707	7	41000.	1.28	38.32
ORD	LAX	25	1409.0	10.00	L10	7	41000.	1.24	44.64
ORD	LAX	27	1409.0	10.00	707	7	41000.	1.28	38.32
ORD	LAX	117	1409.0	10.00	707	7	41000.	1.28	38.32
ORD	LAX	277	1409.0	10.00	707	7	41000.	1.28	38.32
ORD	LGA	306	519.0	1.00	725	7	35000.	.13	2.50
ORD	LGA	310	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	314	519.0	1.00	725	7	35000.	.13	2.50
ORD	LGA	318	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	322	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	326	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	330	519.0	1.00	725	7	35000.	.13	2.50
ORD	LGA	334	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	338	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	342	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	346	519.0	1.00	725	6	35000.	.13	2.50
ORD	LGA	350	519.0	1.00	727	7	35000.	.13	2.29
ORD	LGA	354	519.0	1.00	725	7	35000.	.13	2.50
ORD	OAK	341	1531.0	16.00	727	1	35000.	2.09	36.63
ORD	OAK	341	1531.0	16.00	727	6	35000.	2.09	36.63
ORD	PHL	20	526.0	28.00	B3J	7	41000.	3.45	117.15
ORD	PHL	110	526.0	28.00	L10	7	41000.	3.46	124.98
ORD	PHL	120	526.0	28.00	L10	7	41000.	3.46	124.98
ORD	PHL	238	526.0	28.00	707	7	41000.	3.58	107.30
ORD	PHL	278	526.0	28.00	707	7	41000.	3.58	107.30
ORD	PHX	201	1204.0	11.00	L10	7	41000.	1.36	49.10
ORD	PHX	235	1204.0	11.00	727	7	35000.	1.43	25.19
ORD	PHX	237	1204.0	11.00	727	7	35000.	1.43	25.19
ORD	PHX	241	1204.0	11.00	L10	7	41000.	1.36	49.10
ORD	PHX	435	1204.0	11.00	727	7	35000.	1.43	25.19
ORD	PIT	26	264.0	-2.00	707	7	34960.	-.25	-7.05
ORD	PIT	36	264.0	-2.00	L10	7	34960.	-.25	-10.24
ORD	PIT	104	264.0	-2.00	707	7	34960.	-.25	-7.05
ORD	PIT	158	264.0	-2.00	727	7	34960.	-.26	-4.58
ORD	PIT	270	264.0	-2.00	707	7	34960.	-.25	-7.05
ORD	PIT	250	264.0	-2.00	727	7	34960.	-.26	-4.58
ORD	PIT	290	264.0	-2.00	727	7	34960.	-.26	-4.58
ORD	PIT	292	264.0	-2.00	727	1	34960.	-.26	-4.58
ORD	PIT	292	264.0	-2.00	727	6	34960.	-.26	-4.58
ORD	SFO	131	1513.0	16.00	707	7	41000.	2.05	61.31
ORD	SFO	135	1513.0	16.00	707	1	41000.	2.05	61.31
ORD	SFO	135	1513.0	16.00	707	6	41000.	2.05	61.31
ORD	SFO	175	1513.0	16.00	B3J	7	41000.	1.97	66.94
ORD	SFO	771	1513.0	16.00	L10	7	41000.	1.98	71.42
ORD	TUS	323	1175.0	11.00	725	7	35000.	1.45	27.50
ORD	TUS	339	1175.0	11.00	727	7	35000.	1.43	25.19
ORD	TUS	355	1175.0	11.00	725	1	35000.	1.45	27.50
ORD	TUS	355	1175.0	11.00	725	6	35000.	1.45	27.50
PHL	LAX	37	2026.0	23.00	L10	7	41000.	2.85	102.66
PHL	ORD	27	509.0	16.00	707	7	41000.	2.05	61.31
PHL	ORD	121	509.0	16.00	727	1	35000.	2.09	36.63
PHL	ORD	121	509.0	16.00	727	6	35000.	2.09	36.63
PHL	ORD	179	509.0	16.00	707	7	41000.	2.05	61.31
PHL	ORD	201	509.0	16.00	L10	7	41000.	1.98	71.42
PHL	ORD	711	509.0	16.00	L10	7	41000.	1.98	71.42
PHL	PIT	503	159.0	8.00	DC9	7	30760.	1.04	13.59

TABLE G.6
TRANS WORLD AIRLINES
ENROUTE RNAV BENEFITS ANALYSIS
Continued

ORG A/P	DST A/P	FLT NO	RANGE NMI	RNAV BENE	A/C	F	CRUISE ALT	TIME BENE	FUEL BENE
PHL	PIT	539	159.0	8.00	DC9	7	30760.	1.04	13.59
PHL	PIT	543	159.0	8.00	DC9	7	30760.	1.04	13.59
PHL	PIT	565	159.0	8.00	72S	7	30013.	1.03	21.86
PHL	PIT	755	159.0	8.00	B3J	7	30013.	.96	31.93
PHL	SFO	31	2133.0	25.00	707	7	41000.	3.20	95.80
PHL	STL	101	621.0	3.00	72S	7	35000.	.40	7.50
PHL	STL	451	621.0	3.00	707	7	41000.	.38	11.50
PHX	ABQ	150	200.0	0.00	727	7	32200.	0.00	0.00
PHX	ABQ	170	200.0	0.00	727	7	32200.	0.00	0.00
PHX	JFK	16	1799.0	17.00	B3J	7	41000.	2.09	71.13
PHX	JFK	192	1799.0	17.00	B3J	6	41000.	2.09	71.13
PHX	JFK	192	1799.0	17.00	B3J	1	41000.	2.09	71.13
PHX	LAS	73	140.0	5.00	727	1	29000.	.64	12.69
PHX	LAS	73	140.0	5.00	727	6	29000.	.64	12.69
PHX	LAS	191	140.0	5.00	B3J	7	29000.	.60	20.27
PHX	LAX	17	208.0	3.00	707	7	32627.	.38	10.51
PHX	LAX	133	208.0	3.00	B3J	7	32627.	.36	11.48
PHX	LAX	207	208.0	3.00	727	7	32627.	.39	7.23
PHX	LAX	233	208.0	3.00	72S	6	32627.	.39	7.89
PHX	LAX	233	208.0	3.00	72S	1	32627.	.39	7.89
PHX	ORD	120	1163.0	11.00	L10	7	41000.	1.36	49.10
PHX	ORD	242	1163.0	11.00	727	7	35000.	1.43	25.19
PHX	ORD	354	1163.0	11.00	72S	7	35000.	1.45	27.50
PHX	ORD	358	1163.0	11.00	L10	7	41000.	1.36	49.10
PHX	STL	94	1012.0	2.00	707	7	41000.	.26	7.66
PHX	STL	876	1012.0	2.00	707	4	41000.	.26	7.66
PHX	STL	876	1012.0	2.00	707	3	41000.	.26	7.66
PIT	BOS	248	372.0	24.00	727	7	35000.	3.13	54.95
PIT	BOS	292	372.0	24.00	727	6	35000.	3.13	54.95
PIT	BOS	550	372.0	24.00	DC9	7	34320.	3.16	38.06
PIT	EWR	76	210.0	29.00	707	7	32733.	3.65	101.46
PIT	EWR	158	210.0	29.00	727	7	32733.	3.75	69.75
PIT	EWR	160	210.0	29.00	DC9	7	32200.	3.78	47.84
PIT	EWR	264	210.0	29.00	727	7	32733.	3.75	69.75
PIT	EWR	518	210.0	29.00	DC9	7	32200.	3.78	47.84
PIT	LGA	214	185.0	4.00	DC9	7	31533.	.52	6.69
PIT	LGA	240	185.0	4.00	DC9	7	31533.	.52	6.69
PIT	LGA	246	185.0	4.00	DC9	7	31533.	.52	6.69
PIT	LGA	256	185.0	4.00	DC9	7	31533.	.52	6.69
PIT	LGA	560	185.0	4.00	727	7	31400.	.51	9.81
PIT	LGA	564	185.0	4.00	727	7	31400.	.51	9.81
PIT	LGA	570	185.0	4.00	DC9	7	31533.	.52	6.69
PIT	LGA	572	185.0	4.00	DC9	7	31533.	.52	6.69
PIT	ORD	25	267.0	10.00	L10	7	35080.	1.23	51.16
PIT	ORD	135	267.0	10.00	707	1	35080.	1.27	35.30
PIT	ORD	225	267.0	10.00	727	7	35000.	1.30	22.90
PIT	ORD	235	267.0	10.00	727	7	35000.	1.30	22.90
PIT	ORD	261	267.0	10.00	727	7	35000.	1.30	22.90
PIT	ORD	271	267.0	10.00	707	7	35080.	1.27	35.30
PIT	ORD	277	267.0	10.00	707	7	35080.	1.27	35.30
PIT	PHL	516	144.0	-5.00	DC9	7	30160.	-.65	-8.62
PIT	PHL	520	144.0	-5.00	DC9	7	30160.	-.65	-8.62
PIT	PHL	522	144.0	-5.00	727	7	29213.	-.64	-12.66
PIT	PHL	532	144.0	-5.00	DC9	7	30160.	-.65	-8.62
PIT	PHL	546	144.0	-5.00	DC9	7	30160.	-.65	-8.62
PIT	PHL	548	144.0	-5.00	DC9	7	30160.	-.65	-8.62
PIT	PHL	756	144.0	-5.00	B3J	7	29213.	-.60	-20.21
SDF	LGA	396	508.0	24.00	72S	7	35000.	3.17	60.00
SDF	STL	259	136.0	2.00	72S	7	28680.	.26	5.60
SDF	STL	345	136.0	2.00	707	7	28680.	.25	7.48
SDF	STL	421	136.0	2.00	707	6	28680.	.25	7.48
SFO	BOS	32	2275.0	29.00	L10	7	41000.	3.59	129.45
SFO	DEN	188	726.0	-2.00	727	7	35000.	-.26	-4.58
SFO	DEN	252	726.0	-2.00	727	7	35000.	-.26	-4.58
SFO	DEN	810	726.0	-2.00	B3J	4	41000.	-.25	-8.37
SFO	DEN	810	726.0	-2.00	B3J	3	41000.	-.25	-8.37
SFO	IAD	68	2010.0	7.00	B3J	7	41000.	.86	29.29
SFO	IAD	890	2010.0	7.00	B3J	7	41000.	.86	29.29
SFO	JFK	44	2129.0	26.00	B3J	7	41000.	3.20	108.78
SFO	JFK	806	2129.0	26.00	L10	7	41000.	3.22	116.06
SFO	JFK	842	2129.0	26.00	L10	7	41000.	3.22	116.06
SFO	LAS	176	278.0	29.00	707	7	35520.	3.69	102.65
SFO	LAS	440	278.0	29.00	72S	7	35000.	3.83	72.51
SFO	LAX	6	182.0	3.00	707	7	31240.	.37	10.75
SFO	LAX	76	182.0	3.00	707	7	31240.	.37	10.75
SFO	LAX	90	182.0	3.00	707	7	31240.	.37	10.75
SFO	LAX	92	182.0	3.00	707	7	31240.	.37	10.75
SFO	LAX	232	182.0	3.00	707	1	31240.	.37	10.75
SFO	LAX	232	182.0	3.00	707	6	31240.	.37	10.75
SFO	LAX	306	182.0	3.00	72S	7	31240.	.39	8.05
SFO	LAX	760	182.0	3.00	L10	7	31240.	.36	16.14
SFO	ORD	82	1498.0	16.00	B3J	7	41000.	1.97	66.94
SFO	ORD	130	1498.0	16.00	B3J	7	41000.	1.97	66.94
SFO	ORD	268	1498.0	16.00	707	7	41000.	2.05	61.31
SFO	ORD	770	1498.0	16.00	L10	7	41000.	1.98	71.42
SFO	PHX	94	490.0	32.00	707	7	41000.	4.09	122.63
SFO	PHX	150	490.0	32.00	727	7	35000.	4.17	73.27
SFO	PHX	296	490.0	32.00	707	7	41000.	4.09	122.63
SFO	PHX	358	490.0	32.00	L10	7	41000.	3.96	142.84
SFO	STL	265	1409.0	5.00	72S	7	35000.	.66	12.50
SFO	STL	446	1409.0	5.00	707	7	41000.	.64	19.16
SFO	STL	542	1409.0	5.00	727	7	35000.	.65	11.45
STL	ATL	528	334.0	1.00	DC9	7	33940.	.13	1.60
STL	ATL	562	334.0	1.00	DC9	7	33940.	.13	1.60
STL	ATL	584	334.0	1.00	DC9	7	33940.	.13	1.60
STL	CLE	554	358.0	20.00	DC9	1	34180.	2.63	31.80
STL	CLE	554	358.0	20.00	DC9	6	34180.	2.63	31.80
STL	CLE	578	358.0	20.00	DC9	7	34180.	2.63	31.80
STL	CLE	700	358.0	20.00	72S	7	35000.	2.64	50.00
STL	DAY	80	216.0	4.00	72S	7	33040.	.52	10.45
STL	DAY	524	216.0	4.00	DC9	7	32360.	.52	6.58
STL	DAY	542	216.0	4.00	727	7	33040.	.52	9.57
STL	DCA	374	532.0	4.00	727	7	35000.	.52	9.16
STL	DCA	430	532.0	4.00	72S	7	35000.	.53	10.00
STL	DCA	440	532.0	4.00	72S	7	35000.	.53	10.00
STL	DCA	450	532.0	4.00	727	7	35000.	.52	9.16
STL	DCA	482	532.0	4.00	727	7	35000.	.52	9.16
STL	DEN	401	599.0	0.00	707	7	41000.	0.00	0.00
STL	DEN	451	599.0	0.00	707	7	41000.	0.00	0.00
STL	DEN	457	599.0	0.00	707	7	41000.	0.00	0.00
STL	DEN	561	599.0	0.00	727	7	35000.	0.00	0.00
STL	DTW	210	320.0	27.00	707	7	37160.	3.45	96.74
STL	DTW	244	320.0	27.00	707	7	37160.	3.45	96.74
STL	DTW	566	320.0	27.00	707	7	37160.	3.45	96.74
STL	DTW	832	320.0	27.00	707	4	37160.	3.45	96.74
STL	DTW	832	320.0	27.00	707	3	37160.	3.45	96.74
STL	IND	96	122.0	9.00	707	7	27560.	1.11	34.45
STL	IND	254	122.0	9.00	72S	7	27560.	1.15	25.99
STL	IND	434	122.0	9.00	72S	7	27560.	1.15	25.99
STL	IND	446	122.0	9.00	707	7	27560.	1.11	34.45
STL	IND	454	122.0	9.00	DC9	7	29280.	1.16	15.85
STL	IND	456	122.0	9.00	707	7	27560.	1.11	34.45
STL	LAX	91	1273.0	7.00	707	7	41000.	.89	26.82
STL	LAX	137	1273.0	7.00	707	7	41000.	.89	26.82
STL	LAX	269	1273.0	7.00	72S	7	35000.	.92	17.50
STL	LAX	443	1273.0	7.00	72S	7	35000.	.92	17.50
STL	LGA	56	692.0	2.00	DC9	7	35000.	.26	3.13
STL	LGA	182	692.0	2.00	72S	7	35000.	.26	5.00
STL	LGA	266	692.0	2.00	72S	7	35000.	.26	5.00
STL	LGA	436	692.0	2.00	727	7	35000.	.26	4.58
STL	PHL	498	629.0	3.00	707	7	41000.	.38	11.50
STL	PHL	558	629.0	3.00	72S	7	35000.	.40	7.50
STL	PHX	181	1010.0	2.00	727	1	35000.	.26	4.58
STL	PHX	181	1010.0	2.00	727	6	35000.	.26	4.58
STL	PHX	459	1010.0	2.00	727	7	35000.	.26	4.58
STL	PIT	76	407.0	8.00	707	7	39944.	1.02	30.11
STL	PIT	246	407.0	8.00	DC9	7	34670.	1.06	12.61
STL	PIT	876	407.0	8.00	707	4	39944.	1.02	30.11
STL	PIT	876	407.0	8.00	707	3	39944.	1.02	30.11
STL	SDF	136	136.0	3.00	72S	7	28680.	.39	8.39
STL	SDF	260	136.0	3.00	707	7	28680.	.37	11.22
STL	SDF	444	136.0	3.00	707	7	28680.	.37	11.22
STL	SFO	139	1440.0	14.00	707	7	41000.	1.79	53.65
STL	SFO	223	1440.0	14.00	707	7	41000.	1.79	53.65
STL	SFO	447	1440.0	14.00	72S	7	35000.	1.85	35.00
STL	TUL	107	217.0	0.00	707	7	33080.	0.00	0.00
STL	TUL	187	217.0	0.00	707	1	33080.	0.00	0.00
STL	TUL	187	217.0	0.00	707	6	33080.	0.00	0.00
STL	TUL	495	217.0	0.00	727	7	33080.	0.00	0.00
TPA	MIA	478	103.0	18.00	72S	7	26040.	2.29	54.43
TPA	MIA	492	103.0	18.00	72S	7	26040.	2.29	54.43
TUL	STL	232	218.0	2.00	707	6	33120.	.25	6.97
TUL	STL	436	218.0	2.00	727	7	33120.	.26	4.78
TUL	STL	460	218.0	2.00	707	7	33120.	.25	6.97
TUS	ORD	106	1378.0	11.00	72S	7	35000.	1.45	27.50
TUS	ORD	334	1378.0	11.00	727	7	35000.	1.43	25.19
TUS	ORD	438	1378.0	11.00	727	7	35000.	1.43	25.19

TABLE G.7

RNAV Benefits over VOR for 2/1/76 schedule and route structure

NAL

		ANNUAL				PER AIRCRAFT				
Aircraft Type	Benefit	Fuel (gal)	Time (min)	$ Range Low	$ Range High	# of Aircraft	Fuel (gal)	Time (min)	$ Range Low	$ Range High
727	2D Enroute	145K	7K	67K	115K	13	11.2K	609	5,409	9,190
	2D TMA	651K	34K	306K	521K		50.1K	2603	23,508	39,932
	3D TMA	214K	10K	94K	160K		16.4K	752	7,138	12,114
	Total	1,010K	51K	467K	796K		77.7K	3964	36,055	61,236
72S	2D Enroute	876K	40K	400K	670K	25	35.0K	1616	16,082	26,936
	2D TMA	1,494K	72K	705K	1,180K		59.8K	2865	28,097	47,068
	3D TMA	496K	21K	216K	362K		19.8K	841	8,652	14,490
	Total	2,866K	133K	1,321K	2,212K		114.6K	5322	52,831	88,494
D10	2D Enroute	1,049K	29K	437K	814K	15	70.2K	1876	28,793	53,562
	2D TMA	1,100K	34K	490K	918K		73.3K	2264	32,664	61,157
	3D TMA	221K	6K	91K	170K		14.8K	423	6,301	11,758
	Total	2,370K	69K	1,018K	1,902K		159.3K	4563	67,758	126,477

TABLE G.8

RNAV Benefits over VOR for 2/1/76 Schedule and Route structure

EAL

		ANNUAL					PER AIRCRAFT			
Aircraft Type	Benefit	Fuel (gal)	Time (min)	$ Range Low	$ Range High	# of Aircraft	Fuel (gal)	Time (min)	$ Range Low	$ Range High
L10	2D Enroute	691K	18K	273K	687K	30	23.1K	607	9,202	23,248
	2D TMA	1498K	41K	610K	1552K		49.9K	1382	20,475	52,146
	3D TMA	227K	6K	91K	230K		7.6K	198	3,015	7,606
	Total	2416K	65K	974K	2569K		80.6K	2187	32,692	83,000
727	2D Enroute	2.20M	122K	1.24M	2.02M	75	29.4K	1631	16,544	26,975
	2D TMA	3.10M	162K	1.68M	2.73M		41.3K	2161	22,344	36,449
	3D TMA	.89M	41K	.44M	.72M		11.9K	544	5,896	9,627
	Total	6.19M	325K	3.36M	5.47M		82.6K	4336	44,784	73,051
72S	2D Enroute	1.39M	70K	.647M	1.114M	39	35.5K	1800	16,566	28,570
	2D TMA	2.36M	120K	1.103M	1.902M		60.5K	3066	28,213	48,657
	3D TMA	.67M	28K	.279M	.480M		17.2K	729	7,215	12,414
	Total	4.42M	218K	2.029M	3.496M		113.2K	5595	51,994	89,641
DC9	2D Enroute	147K	12K	77K	138K	8	18.3K	1471	9,427	16,922
	2D TMA	322K	25K	162K	291K		40.2K	3169	20,440	36,672
	3D TMA	179K	11K	78K	139K		22.4K	1429	9,986	17,819
	Total	648K	48K	317K	568K		80.9K	6069	39,853	71,413
D9S	2D Enroute	1.97M	157K	1.15M	1.90M	73	27.1K	2157	15,692	26,094
	2D TMA	3.37M	229K	1.76M	2.92M		46.2K	3136	24,048	39,993
	3D TMA	1.44M	89K	.71M	1.17M		19.7K	1213	9,631	16,018
	Total	6.78M	475K	3.62M	5.99M		92.9K	6506	49,371	82,105

TABLE G.9

RNAV Benefits over VOR for 2/1/76 Schedule and Route Structure

DAL

		ANNUAL				PER AIRCRAFT				
Aircraft Type	Benefit	Fuel (gal)	Time (min)	$ Range Low	$ Range High	# of Aircraft	Fuel (gal)	Time (min)	$ Range Low	$ Range High
D8F	2D Enroute	321K	9K	121K	194K	21	15.3K	461	5,859	9,427
	2D TMA	425K	15K	178K	285K		20.2K	705	8,383	13,451
	3D TMA	173K	5K	65K	104K		8.2K	234	3,052	4,913
	Total	919K	29K	364K	583K		43.7K	1400	17,294	27,791
747	2D Enroute	143K	3.75K	60K	161K	3	47.3K	859	16,564	41,468
	2D TMA	213K	4.0K	76K	191K		70.9K	1458	26,443	67,610
	3D TMA	22K	.3K	7K	16K		7.2K	112	2,347	5,720
	Total	378K	8.1K	143K	250K		125.4K	2429	45,354	114,798
L10	2D Enroute	1.28M	34K	527K	1.34M	18	71.0K	1882	29,184	73,894
	2D TMA	1.49M	44K	652K	1.68M		82.9K	2419	36,007	92,481
	3D TMA	.30M	8K	124K	.31M		16.4K	430	6,700	16,939
	Total	3.07M	86K	1303K	3.33M		170.3K	731	71,891	183,314
D8S	2D Enroute	858K	24K	330K	585K	13	66.0K	1885	25,581	45,316
	2D TMA	938K	30K	387K	687K		72.1K	2269	29,466	52,337
	3D TMA	280K	7K	101K	179K		21.5K	562	7,954	14,056
	Total	2074K	61K	818K	1451K		159.6K	4716	63,001	111,709
727	2D Enroute	2.89M	145K	1.31M	2.40M	76	38.0K	1907	17,200	31,580
	2D TMA	4.45M	226K	2.03M	3.73M		58.6K	2974	26,707	49,055
	3D TMA	1.45M	62K	.60M	1.09M		19.1K	815	7,866	14,355
	Total	8.79M	433K	3.94M	7.22M		115.7K	5696	51,773	94,990
DC9	2D Enroute	1.26M	97K	598K	1.09M	62	20.3K	1562	9,636	17,484
	2D TMA	2.19M	147K	958K	1.73M		35.2K	2377	15,447	27,912
	3D TMA	1.60M	99K	668K	1.20M		25.8K	1590	10,739	19,347
	Total	5.05M	343K	2224K	4.02M		81.3K	5529	35,822	64,743

TABLE G.10
RNAV Benefits over VOR for 2/1/76 Schedule and Route Structure

AAL

Aircraft Type	Benefit	ANNUAL Fuel (gal)	ANNUAL Time (min)	ANNUAL $ Range Low	ANNUAL $ Range High	# of Aircraft	PER AIRCRAFT Fuel (gal)	PER AIRCRAFT Time (min)	PER AIRCRAFT $ Range Low	PER AIRCRAFT $ Range High
707	2D Enroute	2.47M	82K	1059K	1.98M	88	28.1K	933	12,060	22,511
	2D TMA	2.73M	100K	1241K	2.33M		31.0K	1135	14,092	26,420
	3D TMA	.96M	30K	398K	.74M		10.9M	341	4,519	8,413
	Total	6.16M	212K	2698K	5.05M		70.0K	2409	30,671	57,344
727	2D Enroute	3.99M	227K	1995K	3.55M	106	37.6K	2135	18,802	33,496
	2D TMA	5.47M	263K	2466K	4.38M		51.6K	2477	23,242	41,241
	3D TMA	1.35M	62K	592K	1.05M		12.7K	583	5,570	9,873
	Total	10.81M	552K	5053K	8.98M		101.9K	5195	47,614	84,610
D10	2D Enroute	1.03M	30K	475K	.91M	25	41.0K	1195	19,130	36,697
	2D TMA	1.22M	36K	574K	1.10M		48.7K	1449	23,016	44,194
	3D TMA	.21M	6K	97K	.19M		8.2K	237	3,807	7,299
	Total	2.46M	72K	1146K	2.20M		97.9K	2881	45,953	88,190
747	2D Enroute	-.04M	-1.0K	-30K	-.057M	10	-4.0K	-73	-2,417	-4,497
	2D TMA	.14M	3.0K	95K	.178M		14.2K	269	8,810	16,410
	3D TMA	.01M	.1K	4K	.008M		.6K	10	341	632
	Total	.11M	2.1K	69K	.129M		10.8K	206	6,734	12,545

TABLE G.11

RNAV Benefits over VOR for 2/1/76 Schedule and Route Structure

UAL

		ANNUAL					PER AIRCRAFT			
Aircraft Type	Benefit	Fuel (gal)	Time (min)	$ Range Low	$ Range High	# of Aircraft	Fuel (gal)	Time (min)	$ Range Low	$ Range High
727	2D Enroute	4.25M	236K	2.17M	2.68M	122	34.8K	1934	17,731	30,154
	2D TMA	3.16M	156K	1.49M	2.54M		25.9K	1282	12,269	20,846
	3D TMA	1.37M	63K	.62M	1.05M		11.3K	515	5,090	8,643
	Total	8.78M	455K	4.28M	7.27M		72.0K	3731	35,090	59,643
72S	2D Enroute	1.10M	57K	533K	945K	28	39.4K	2041	19,100	33,829
	2D TMA	.95M	42K	418K	738K		34.0K	1515	15,033	26,537
	3D TMA	.48M	20K	204K	360K		17.1K	725	7,343	12,948
	Total	2.53M	119K	1155K	2043K		90.5K	4281	41, 476	73,314
737	2D Enroute	1.42M	120K	948K	1.56M	64	22.1K	1874	14,785	24,277
	2D TMA	1.29M	95K	780K	1.28M		20.2K	1481	12,176	20,006
	3D TMA	.84M	56K	474K	.78M		13.2K	883	7,468	12,275
	Total	3.55M	271K	2202K	3.62M		55.5K	4238	34,429	56,558
D10	2D Enroute	1.31M	38K	622K	1.22M	37	35.3K	1048	16,856	32,221
	2D TMA	1.61M	48K	711K	1.52M		43.6K	1290	20,791	40,966
	3D TMA	.33M	9K	150K	.29M		8.8K	177	3,360	6,466
	Total	3.25M	95K	1543K	3.03M		87.7K	2515	41,007	79,653
DC8	2D Enroute	1.61M	50K	622K	1.12M	53	30.2K	944	11,673	21,154
	2D TMA	1.66M	55K	662K	1.20M		31.3K	1045	12,531	22,766
	3D TMA	.46M	13K	169K	.30M		8.7K	247	3,196	5,772
	Total	3.73M	118K	1453K	2.62M		70.2K	2236	27,400	49,692
D8S	2D Enroute	1.37M	26K	406K	785K	39	34.9K	645	10,312	19,913
	2D TMA	.99M	31K	371K	750K		25.4K	786	9,471	19,109
	3D TMA	.44M	13K	160K	322K		11.3K	333	4,110	8,257
	Total	2.80M	70K	937K	1857K		71.6K	1764	23,893	47,279
747	2D Enroute	.38M	7K	142K	274K	18	21.4K	381	8,037	15,511
	2D TMA	.51M	10K	202K	392K		28.2K	562	11,258	21,882
	3D TMA	.06M	1K	22K	42K		3.4K	53	1,195	2,286
	Total	.95M	18K	366K	679K		53.0K	996	20,490	39,679

TABLE G.12

RNAV Benefits over VOR for 2/1/76 Schedule and Route Structure

TWA

		ANNUAL				# of Aircraft	PER AIRCRAFT			
Aircraft Type	Benefit	Fuel (gal)	Time (min)	$ Range Low	$ Range High		Fuel (gal)	Time (min)	$ Range Low	$ Range High
L10	2D Enroute	1095K	29.5K	464K	1003K	30	36.5K	1002	15,613	33,864
	2D TMA	828K	22K	348K	752K		27.6K	738	11,635	25,168
	3D TMA	151K	4K	63K	137K		5.0K	132	2,092	4,521
	Total	2074K	55.5K	875K	1892K		69.1K	1872	29,340	63,553
727	2D Enroute	976K	55K	519K	878K	35	27.9K	1575	14,813	25,065
	2D TMA	1329K	61K	618K	1045K		38.0K	1752	17,732	29,971
	3D TMA	380K	17K	174K	294K		10.8K	496	5,027	8,498
	Total	2685K	133K	1311K	2217K		76.7K	3823	37,572	63,534
72S	2D Enroute	1558K	81K	696K	1356K	39	40.0K	2061	17,839	34,722
	2D TMA	1686K	73K	681K	1311K		43.2K	1870	17,438	33,592
	3D TMA	554K	24K	224K	431K		14.2K	603	5,672	10,913
	Total	3798K	178K	1601K	3098K		97.4K	4534	40,949	79,227
DC9	2D Enroute	484K	39K	323K	564K	18	26.9K	2181	18,037	31,479
	2D TMA	716K	48K	419K	730K		39.8K	2692	23,450	40,834
	3D TMA	250K	16K	142K	247K		13.9K	885	7,856	13,669
	Total	1450K	103K	884K	1541K		80.6K	5758	49,343	85,982
707	2D Enroute	3.06M	98K	1.20M	2.14M	100	30.6K	990	11,974	21,454
	2D TMA	2.88M	99K	1.17M	2.09M		28.8K	994	11,678	20,966
	3D TMA	1.01M	30K	.38M	.68M		10.1K	302	3,791	6,775
	Total	6.95M	227K	2.75M	4.91M		69.5K	2286	27,443	49,195
747	2D Enroute	25K	.5K	9K	23K	10	.25K	5	92	234
	2D TMA	67K	1.4K	25K	65K		6.72K	140	2,523	6,466
	3D TMA	6K	.1K	2K	5K		.62K	10	205	504
	Total	98K	2.0K	36K	93K		7.59K	155	2,820	7,204

TABLE G.13

NAL

4D RNAV PROJECTED BENEFITS

Aircraft Type	ANNUAL				PER AIRCRAFT				
	Fuel (gal)	Time (min.)	$ Range		# of Aircraft	Fuel (gal)	Time (min.)	$ Range	
			Low	High				Low	High
727	396K	27K	222K	377K	13	30.5K	2077	17,045	29,008
72S	968K	60K	537K	900K	25	38.7K	2400	21,490	36,016
D10	1425K	52K	734K	1327K	15	95.0K	3467	46,913	88,473

TABLE G.14

EAL

4D RNAV PROJECTED BENEFITS

Aircraft Type	ANNUAL				PER AIRCRAFT				
	Fuel (gal)	Time (min.)	$ Range		# of Aircraft	Fuel (gal)	Time (min.)	$ Range	
			Low	High				Low	High
L10	1163K	40K	542K	1425K	30	38.8K	1333	18,067	47,497
727	2825K	190K	1820K	2963K	75	37.7K	2533	24,260	39,504
72S	2217K	136K	1167K	2018K	39	56.8K	3487	29,935	51,751
DC9	441K	44K	264K	476K	8	55.8K	5500	32,952	59,442
D9S	2571K	241K	1672K	2780K	73	35.2K	3301	22,901	38,077

TABLE G.15

DAL

4D RNAV PROJECTED BENEFITS

Aircraft Type	ANNUAL				PER AIRCRAFT				
	Fuel (gal)	Time (min.)	$ Range		# of Aircraft	Fuel (gal)	Time (min.)	$ Range	
			Low	High				Low	High
D8F	941K	41K	445K	712K	21	44.8K	1952	21,212	33,910
747	411K	10K	168K	441K	3	137.0K	3333	55,938	147,044
L10	2499K	86K	1199K	3153K	18	138.8K	4778	66,636	175,189
D8S	1381K	54K	641K	1145K	13	106.2K	4154	49,306	88,085
727	4863K	301K	2511K	4644K	76	64.0K	3961	33,036	61,112
DC9	2512K	235K	1353K	2469K	62	40.5K	3790	21,822	39,824

TABLE G.16

AAL

4D RNAV PROJECTED BENEFITS

Aircraft Type	ANNUAL				PER AIRCRAFT				
	Fuel (gal)	Time (min.)	$ Range		# of Aircraft	Fuel (gal)	Time (min.)	$ Range	
			Low	High				Low	High
707	4391K	207K	2343K	4440K	88	49.9K	2352	26,624	50,449
727	5722K	385K	3199K	5721K	106	54.0K	3632	30,177	53,968
D10	2087K	77K	1133K	2198K	25	83.5K	3080	45,313	87,927
747	131K	3K	93K	175K	10	13.1K	300	9,333	17,480

TABLE G.17

UAL

4D RNAV PROJECTED BENEFITS

Aircraft Type	ANNUAL				PER AIRCRAFT				
	Fuel (gal)	Time (min.)	$ Range		# of Aircraft	Fuel (gal)	Time (min.)	$ Range	
			Low	High				Low	High
727	5051K	340K	2926K	4983K	122	41.4K	2787	23,988	40,847
72S	1696K	104K	917K	1630K	28	60.5K	3714	32.755	58,224
737	1849K	182K	1382K	2268K	64	28.9K	2844	21,599	35,446
D10	2598K	95K	1421K	2833K	37	70.2K	2568	38,400	76,567
DC8	2900K	125K	1347K	2470K	53	54.7K	2358	25,415	46,604
D8S	2023K	80K	863K	1776K	39	51.9K	2051	22,123	45,544
747	1192K	30K	545K	1074K	18	66.2K	1667	30,253	59,672

TABLE G.18

TWA

4D RNAV PROJECTED BENEFITS

Aircraft Type	ANNUAL				PER AIRCRAFT				
	Fuel (gal)	Time (min.)	$ Range		# of Aircraft	Fuel (gal)	Time (min.)	$ Range	
			Low	High				Low	High
L10	1564K	54K	769K	1705K	30	52.1K	1800	25,644	56,830
727	1406K	95K	844K	1429K	35	40.2K	2714	24,105	40,823
72S	1856K	114K	923K	1815K	39	47.6K	2923	23,669	46,528
DC9	405K	40K	315K	551K	18	22.5K	2222	17,494	30,602
707	4489K	206K	2154K	3901K	100	44.9K	2060	21,539	39,011
747	70K	2K	31K	85K	10	7.0K	200	3,137	8,457

APPENDIX H

FIELD CONTROLLER APPRAISAL OF THE USE OF RNAV/VNAV IN TERMINAL AREA ATC OPERATIONS

H.1 INTRODUCTION

Considerable interest has been expressed by various groups in the involvement of journeymen air traffic controllers, drawn from field facilities, in this simulation in which RNAV/VNAV operations are introduced into a high density terminal ATC environment. The purpose of the introduction of field controllers in the training, exploratory, and data collection phases of the simulation served four major purposes: (1) to draw upon our current field experience in the refinement of the environment/procedures to be simulated, (2) to solicit our comments and reactions to the use of RNAV/VNAV in terminal area operations, (3) to derive quantitative simulation results from data collection runs in which we participated as test subjects, and (4) to provide us with some degree of familiarity with RNAV/VNAV operations through simulations.

Through the cooperation of the Air Traffic Service, Washington, D.C., and the regions and facilities represented, we were detailed to NAFEC to participate in the simulation. While NAFEC pool controllers also participated in the simulation, due to the high degree of interest expressed in our participation, the following appraisal represents our opinions only. The presentation of our appraisal, independent of any comments or opinion expressed by the NAFEC pool controllers, is provided to be responsive to this interest and does not imply any prejudicial judgment between the value to NAFEC pool controllers and our opinions.

H.2 BACKGROUND

We started the training phase in the operational use of RNAV/VNAV at NAFEC on June 16, 1975. The purpose of the training phase was to familiarize the digitial simulation facility (DSF) target generator operators (DSF pilots), general aviation trainer (GAT) pilots, and the air traffic controllers with all required aspects of the simulation including geography, equipment and procedures. The training phase was scheduled to be followed by an exploratory phase during which the initial procedures, geography, etc. could be modified and refined prior to the data collection phase which was scheduled to start no later than August 4. Due to the numerous problems in the shakedown of the simulation equipment, the planned training and exploratory phase were frequently disrupted by various simulation system performance problems and failures and data collection was delayed until August 18, 1975. The need for extensive shakedown runs impacted severely on controller training and the exploratory phases of the simulation. The failure of the DSF targets to react in a predictable manner to ATC clearances (due to problems in the DSF not associated with "real world" RNAV/VNAV performance) worked to the detriment of an early understanding and efficient use of RNAV/VNAV functions in the control of air traffic. There may be a residual effect of this uncertainty as to compliance with ATC clearances and anomalous performance of the simulated targets which will impact

the objective results from the data runs. However, the opinions upon which the following
of the data collection period and are expressions of our subjective analysis of the operational application of RNAV/VNAV to terminal air traffic control.

H.3 TERMINAL AREA RNAV ROUTE STRUCTURE DESIGN (2D)

It is our opinion that the RNAV (2D) structure design originally planned for simulation required some modification to provide a higher degree of flexibility for the controller, if such modifications did not adversely impact route miles, altitude restrictions, etc. to an undue extent on the system user. A modified design was developed which appeared to satisfy this requirement. The major difference between this design, which was developed during the exploratory period for use in data collection runs, and the original design was in the area immediately to the east of JFK. The original design located the departure routes serving departures to the northwest, north and northeast parallel to, and inside the downwind leg. The new design, which is discussed in more detail in the NAFEC simulation report, placed the departure routes outside the downwind leg. This change appeared to have no adverse impact on the system user. The modification was made based on the following operational consideration:

> There was a need for radar vectoring airspace, so that we could compare a 100 percent radar vectored operation with a 100 percent RNAV/VNAV operation. We would have been unable to compare these operations if we had to vector aircraft along the RNAV track.
>
> The original design was made by Champlain Technology Industries, and there were no provisions made for radar vectored aircraft in their design.
>
> The arrival route was moved inside the departures to give us more flexibility. We wanted to have the ability to shortcut traffic to runway 22L, from the downwind leg. This gave the final controller a true dump zone.
>
> The new design had more waypoints. Two of the new waypoints were positioned closer to the outer marker. This enabled the final controller to switch any arrival to either runway by the use of RNAV.

H.4 TERMINAL AREA VNAV ROUTE STRUCTURE DESIGN (3D)

The original design planned for simulation allowed for the use of "stacked routes" for arrival/departure traffic. (The term "stacked routes" is used here to describe two or more routes having common or near common horizontal paths which are separated vertically based on VNAV (3D) separation criteria.) It was envisioned that a unique application of VNAV arrival routes would result through the use of two-segment approaches which were to be included in certain parts of the simulation tests. However, when it was learned that the FAA did not support the use of two-segment approaches, this application was no longer considered viable. Therefore a renewed and major emphasis was placed on determination of other potential uses for VNAV and its unique capabilities

as they might relate to both terminal airspace design and ATC operational use of VNAV as a control tool.

In order to clarify the unique use of VNAV in combination with the two-segment approach concept, and why this combination appeared to offer some potential advantage in the use of stacked routes, the following illustration (Figure H.1) is provided. As shown, using a two-segment approach to runway 22R and a single-segment approach to runway 22L, traffic from the east could fly stacked routes with the aircraft on the higher route intercepting the localizer for runway 22R at a higher altitude and executing a two-segment approach. The aircraft on the lower stacked routes would intercept the localizer for runway 22L at a lower altitude and vertical separation could be provided between the two aircraft until both were established on their respective localizers. Since two-segment approaches were dropped from the simulation tests it is not known whether this combination would provide any operational advantage or not. However, two-segment approaches, when used as illustrated, did appear to provide a means for "unstacking" stacked routes.

Our efforts to develop discrete VNAV routes was not limited to stacked routes but was an extension of the previous work done by Champlain Technology Industries in their terminal route design activities and other analyses by SRDS and NAFEC prior to and during simulation planning. While the capabilities of VNAV were recognized by us as potentially beneficial to the ATC system user, it was the consensus that the only unique, potentially advantageous, property of VNAV related to terminal airspace is the capability to define the vertical dimension of a path through space as though the path were described with an infinite number of altitude checkpoints.

A number of applications of VNAV to route structure design were considered. During these studies we were advised not to consider either the original or modified route structures as a constraint to the development of routes discrete to VNAV operations. We were in effect given complete freedom to invent any route that potentially would exploit the use of VNAV. The effort was aimed at defining a route or series of routes that, by their nature, could be used exclusively by VNAV equipped flights rather than routes that could be used by both RNAV and VNAV equipped traffic. This approach was taken to identify any airspace design application based on the unique capabilities of VNAV.

As a result of this effort, no VNAV-only charted route structure or individual routes were developed. It was our opinion that no need or advantage could be found in airspace design for discrete VNAV-only routes. It was concluded that a good terminal route structure would accommodate both RNAV and VNAV traffic.

H.5 RNAV ATC APPLICATION

The following represents our opinions as to the advantages, disadvantages and limitations to the use of RNAV in terminal ATC operations. These opinions presuppose that certain conditions relative to avionics equipment and pilot performance are met.

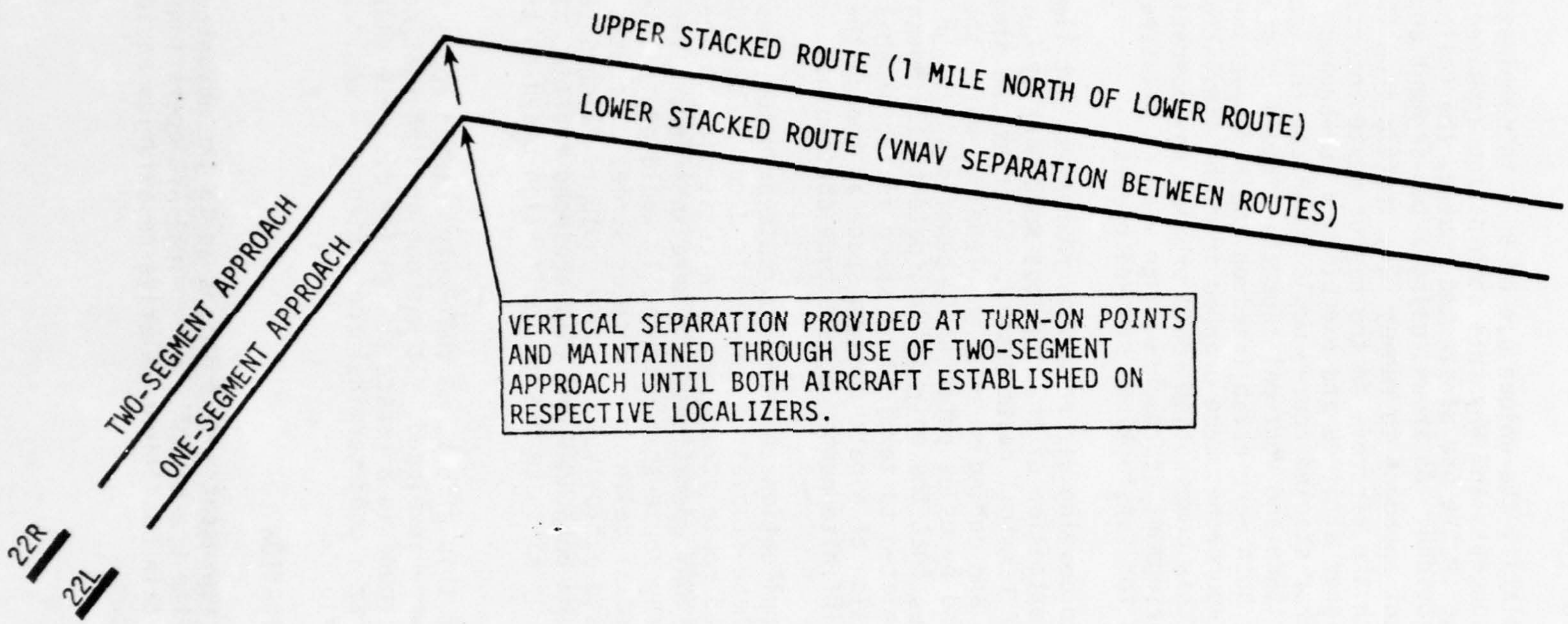


Figure H.1 EXAMPLE OF STACKED ROUTE/TWO-SEGMENT APPROACH APPLICATION

Conditions - (1) RNAV turn anticipation (both automatic and manual) will be performed in such a manner that the approximate ground track can be anticipated by the controller. This assumes that both automatic and manual turn anticipation procedures be standarized to minimize the requirement for radar vectoring to compensate for turns that deviate from the expected ground path.

(2) All RNAV flights will be capable of flying at least a ten-mile parallel offset.

(3) All turns to and from offsets will be accomplished using a common departure angle from the parent/offset route unless otherwise specified by the controller.

(4) All RNAV equipment will permit assignment of "direct to" waypoint clearances and compliance with such instructions will result in the aircraft flying a direct path to the assigned waypoint upon completion of any required turn.

(5) Offsets may be cancelled prior to the time the aircraft achieves the assigned parallel offset distance from the parent track.

(6) Flights on a "direct to" clearance can be assigned an offset parallel to the direct flight path.

(7) All RNAV functions simulated will be available.

(8) Charted SIDs and STARs with altitude restrictions are published and that such SIDs and STARs are so designed as to provide flexibility for spacing and sequencing of traffic equivalent to that required in a radar vector operational environment.

While condition (6) was not met by the DSF targets, condition (6) is believed to be realistic and available in some, if not all, RNAV systems, and our appraisal of the use of RNAV in terminal operations assumes that all of the preceding conditions would be met. This appraisal, based on both experience in the NAFEC simulation and in current field facility terminal air traffic control, is organized by specific areas of potential ATC impact and summarized in a general appraisal statement.

Controller Radio Communications - We feel that there would be some reduction in radio communications for the feeder controllers in a 100 percent RNAV/VNAV operation.

There would be a greater reduction of radio communications in a 100 percent RNAV/VNAV departure operation. However, there was minor reduction on the final control positions.

The reason for the reduced communications is that each SID departure or STAR arrival has a predetermined route to fly with all the altitude restrictions on it. The controller need only monitor the flight and make occasional RNAV maneuvers to accommodate overtaking or merging traffic situations.

The Role of RNAV Maneuvers vs. Phase of Flight - RNAV Limitations: Because of differences in navigational error and turn anticipation, separation standards in critical areas such as base leg or turns to final, can, and often do, diminish separation to less than prescribed minimums. Whereas radar vectors, being more precise when employed properly, can be benefically substituted in these same areas to provide more exact required separation.

Impact of Mixes of RNAV/Non-RNAV Operations - Both the departure and feeder controllers found no appreciable differences between mixed traffic situations. It was just as easy to assign a heading off a fix or off the runway, as it was to issue an RNAV maneuver. However, the final controller's workload increases if he incorporates RNAV instructions for the RNAV aircraft and vectors to the non-RNAV aircraft.

Impact of Mixes of VNAV/RNAV Operations - No differences noted.

System Capacity - RNAV will not affect traffic capacity in the terminal area, in that it is possible to run a three-mile final with RNAV or with radar vectors. Present day standards require three-mile separation and this can be accomplished with or without RNAV.

General Appraisal Statement - It is our opinion that RNAV/VNAV procedures may well be applied in the terminal area to provide a safe, orderly and expeditious flow of air traffic. We feel that RNAV routes with altitude restrictions to which VNAV usage can be applied, as pilots may desire, should be established at as many busy terminal areas as may be deemed beneficial by FAA and user groups. We feel that these routes should initially co-exist with established airspace allocations to the maximum extent possible to insure little or no adverse impact on present day operations. We also feel strongly that radar vector procedures should be employed at the discretion of the controller in critical areas where RNAV/VNAV may not be as precise as radar. We believe that RNAV/VNAV will be beneficial to the user in that properly established routes can and will reduce flying miles and time. It will be beneficial to the user and more particularly to the controller under all traffic densities, in that the controller will normally have to provide fewer control instructions, subsequently allowing him to perform duties which may include handling more aircraft per sector, combining sectors or portions of sectors, and freeing him to provide both essential and additional services at a reasonable level.

It is felt that RNAV/VNAV could work well in a high density terminal area. RNAV STARs should be made for the entire route of flight including the final approach. RNAV/VNAV could be used to set up straight-in approaches to satellite airports that have no navigational aids.

VNAV ATC APPLICATION

The following represents our opinions as to the advantages, disadvantages and limitations to the use of VNAV in terminal operations.

During the pre-data collection and data collection periods of the simulation, little or no operational use was made of the functions peculiar to

VNAV. While those functions common to both RNAV and VNAV were used to a major degree, there were no occasions found for the use of VNAV as a control tool. In addition, it was our opinion that while VNAV capabilities have the potential for providing advantages to the user in the manner in which climbs and descents can be accomplished, these potential advantages do not require the establishment of exclusively VNAV routes. Such advantages are available in a well structured RNAV terminal route system.

When VNAV vertical separation is being applied between aircraft on crossing courses, vertical separation criteria are predicated upon mathematical curves, which increase separation requirements proportionately with any change of the course angle convergence or divergence, and any increase of degree of vertical path angle. These VNAV separation standards can only increase the present day minimums which dictate one thousand feet vertical separation between IFR aircraft and which can more efficiently and effectively be applied through step-up or step-down procedures in use today. Also due to the complex nature of the mathematical curve, a controller could very rarely move an aircraft laterally from an established track and still insure separation from a crossing course. Impromptu courses would be out of the question, as altitude separation requirements could not possibly be computed by the controller.

When VNAV vertical separation is being applied between aircraft in a parallel climb or descent on the same lateral track, separation criteria in accordance with the Vertical Separation Requirements curves is increased over criteria which can be applied through the use of today's step-up or step-down procedures. If an aircraft is moved laterally from the main track, separation from another aircraft, which had previously been separated by the minimum criteria, either above or below, immediately ceases to exist due to the proportionate vertical separation increase caused by course angle divergence in the mathematical curve. Impromptu courses would again be out of the question, as controllers could not compute descent angles or altitude separation requirements.

VNAV could be used as a useful tool to pilots as a more economical means of climb or descent.

RNAV/VNAV could be used to set up straight-in approaches to satellite airports that have no navigational aids. It could also be used to set up an artifical glide path to aid in VOR approaches, which would possibly lower minimums.

The foregoing appraisal represents the expressed opinions of the following named field controllers who participated in the NAFEC RNAV/VNAV simulation and is based on our experience in the simulation and our judgments as current field facility air traffic control specialists.

[Signed]

D. B. CARLSON	Atlanta Tower
JULES M. ROSENTHAL	New York Common IFR Room
GERALD R. FROST, JR	Bradley Tower
KEN ANDERSON	Minneapolis Tower
KURT A. WILLIAMS	Houston Tower

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